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THE ANATOMY AND DEVELOPMENT OF THE Lateral Line System in Amia Calva.

BY

EDWARD PHELPS ALLIS, JR.

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THE ANATOMY AND DEVELOPMENT OF THE LATERAL LINE SYSTEM IN AMIA CALVA.

EDWARD PHELPS ALLIS, JUNR.

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CONTENTS.

THE general course and position of the lateral canals in fishes have long been known, and short descriptions and diagrams, showing what is commonly accepted as the typical arrangement of the main canals, are given in nearly all modern text-books of vertebrate anatomy. More complete descriptions are given in numerous special works, most of which deal more particularly with other subjects, such as the structure of the skull, the

development and distribution of the cranial nerves, or the histology and function of the sense-organs.

With a few exceptions, all these descriptions, so far as they relate to the cranial part of the lateral system, are of a general character only, giving little more than the course of the main canals. The development of the canals, the number and position of the organs, and their innervation, receive but scant attention. This has doubtless been largely due, as Merkel suggests, to the difficulties attending this part of the investigation before the introduction and perfection of modern methods of research; but this cannot have been the only reason, for most of the work could easily have been done by any of the earlier writers. The purely descriptive part of the subject seems simply to have been neglected in the greater interest attaching to the histological and physiological sides, so that it is only within the last five or six years that the constant relations of the cranial canals to the dermal bones of the head, and their importance in determining these bones in doubtful cases, have been recognized. Both Sagemehl and Van Wijhe have called special attention to this, and Sagemehl further says (No. 12, p. 182, note) that the lateral canals seem to deserve a more careful study than has hitherto been given them.

In Amia calva the cranial canals have been oftener and more fully described than in any other form. Franque (No. 6), in 1847, in a dorsal view of the dermal bones of the head, shows some of the surface openings of these canals, but in the text he does not refer to them, these four words only being found, "Linea lateralis fere recta" (No. 14, p. 368). Bridge (No. 4, p. 620), thirty years afterward, in describing the skull, gave the course and position of the main canals, the connections they form with one another, and the bones they traverse, and the arrangement given by him agrees closely with that more fully detailed in the present paper. His work was mainly confirmed in 1882 by Van Wijhe (No. 17, p. 288), and in 1883 and 1884 by Sagemehl (No. 12, p. 183, and No. 13, p. 36); still later by Shufeldt (No. 15), in connection with his translation of Sagemehl's paper; and finally Wright (No. 18) has called attention to the sensory tissue lying in the upper end of the spiracular canal, and belonging, by its innervation, to the general lateral canal system, though classed by him as hypodermal and exceptional.

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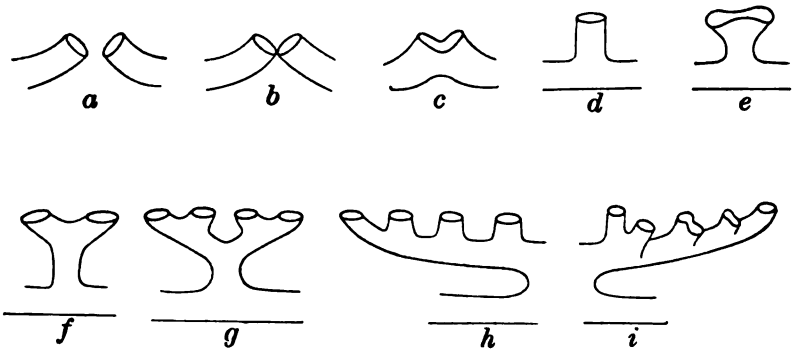
into some one of the dermal bones. In its course it unites with similar canals from other pores, and increasing continually in size, finally becomes a trunk canal, which opens into one of the main lateral canals of the head. This trunk canal and its branches form what has been called a dendritic system, of which the surface pores are the external openings.

The arrangement of these pores varies greatly in different parts of the head. They are found either single or in pairs, in more or less irregular lines, or in irregular groups, the number and arrangement of them differing somewhat in every specimen, and even on opposite sides of the head in the same specimen. As many as thirty-seven hundred were counted on the head of a single large specimen, and the number apparently increases indefinitely with the age of the fish. This great multiplication is the result of a repeated dichtomous division of the pores formed in younger stages. The impulse leading to this division acts with much greater intensity in certain parts of the head than in others, but is felt in all parts; for, with the exception of the large pore at the hind edge of the supraclavicula (Fig. 39, Pl. XXXIX., $i^{2}ll^{1}p$), which marks the limit of the cranial system, there is not a pore on the head of the young fish that is not double in later stages.

In both fresh and alcoholic specimens, the pores have a well-marked whitish border, due mainly to the absence of inter-epithelial pigment cells; and when fully formed they are approximately round. When about to divide, the sides of the oblong and continually lengthening pore grow rapidly upward and toward each other, and the pore becomes hour-glass or dumb-bell-shaped. The projecting sides or lips finally meet and coalesce, and the pore is divided into two pear-shaped portions which lie in a small unpigmented oval space. In this process the canal leading to the pore is also divided into two portions, for an arch is formed across the end of it, and it becomes Y-shaped form as shown in the accompanying diagrammatic figure (Cut 1, *d*, *e*, *f*). The two newly formed pores are at first connected by a whitish cicatrice (Fig. 17, Pl. XXXV.); but the impulse which led to their formation continuing to act, they travel apart, the cicatrice disappears, and they become distinct and perfect pores. One or both of them may again divide in the same manner, and nearly in the same direction as at first, thus giving rise

to a line of pores usually somewhat curved, and to a canal of the form shown in Cut 1, *g*. The division of the terminal pores of such a line may then proceed more rapidly than that of the intermediate ones, thus producing creeper-like canals of the form shown in *h*; or later, divisions may take place at an angle to the original direction of division as shown in *i*, the angle being usually a right one, or nearly so, and then again in the same direction, or in the original direction, thus giving rise to a series of intersecting, or parallel lines, and to a more or less complicated arrangement of pores in groups of different sizes and shapes. There is in this process of multiplication a strong tendency to keep the pores of the different lines and groups at



Cut 1.

Cut 1. — Diagrammatic representation of the formation and subsequent division of a primary pore or tube: *a*, *b* and *c*, two half-pores approaching each other and fusing; *d*, primary pore and tube; *e*, the same, undergoing its first division, which in *f* is completed; *g*, dentritic system after second regular division; *h* and *i*, forms of creeper-like branches.

about the same distance apart, so that when the groups become large, somewhat geometrical designs are formed, and any particular pore may appear to belong to one of two or more intersecting surface lines, either one of which might be taken, from surface indications alone, to be the line of formation of the series.

This is the regular method of multiplication and formation of the pores and branch canals in Amia, none of them being formed by growth from beneath; that is, by the canals first forming there as diverticula, or prolongations of existing canals, and then forcing their way through to the upper surface. Not a

single instance was found of such a growth from below, and but one of the reverse condition, — that of a tube leading blindly inward from the external surface toward a canal; and the conditions in this case seemed to indicate that the tube, after its regular formation, had been closed secondarily below the surface. The specimen in which this was found was taken in winter, through the ice, and having been frozen and frequently handled, the epidermis was so injured before the pit was discovered that it was impossible to tell whether there had originally been a regular surface pore or not.

The formation of the more or less complicated groups of pores resulting from this method of division is well shown in Fig. 17, Pl. XXXV., which represents the head of an Amia about fifteen months old and 11½ inches long. This specimen, which was raised in an aquarium, was much larger than other specimens two years old living in the same aquarium, and probably larger than fishes of the same age found in their native waters; for, according to Dr. Estes (No. 7, p. 659), Amia one year old, taken in the sloughs tributary to Lake Pepin, are only from three to six inches long. All stages in the division of a pore are shown in this figure. In some instances the pore is apparently dividing into three portions instead of two, but this is due to the accelerated re-division of one of the portions before the regular division has been completed. Nothing of this kind was found in any of the several adult fishes examined, but in the skeletons prepared, the openings of the canals on the upper surface of the frontal often presented a tri-lobate appearance, indicating that they had arisen in this manner (Pl. XL., Fig. 40, sg^5, sg^6).

The different groups of pores, although varying greatly in size and shape in different individuals, or even in the same individual on opposite sides of the head, are normally definite in number and general position. Each group when small is confined strictly to some particular region of the head; but in its growth it extends beyond this region, and becomes continuous with neighboring groups. It is necessary, therefore, in order to arrive at the proper number and arrangement of the groups in large and well-developed specimens, to trace the canal leading from each pore to the particular trunk or stem from which it arises.

The system of canals leading from the pores of any one group forms, as already stated, a dendritic structure, the trunk of which is the common connection of the group with some one of the main canals of the head. These main canals lie almost exclusively in the deeper, more porous layer of the dermal bones, near their under surface, and often project in the form of a ridge below the general level of this surface. Bridge (No. 4, pp. 607 and 608) considers this part of the bone in Amia an "adherent parostosis," resulting from the later ossification of the subcutaneous tissues lying immediately under the original ganoid plate, which is represented in the superficial, thinner, and denser layer of the bone. The development, however, shows that the dermal bones grow mainly by accretions to their upper surfaces, and that the deeper portion is the one formed first, the canals in young specimens lying in it or above it, and in no case below it.

In their passage from one bone to another, where the bones are not suturally connected, the canals lie in a dense connective tissue, which forms the deeper part of the cutis. This occurs particularly between the frontal and nasal on either side, and between the upper and lower ends of the pre-operculum and the squamosal and angular respectively.

The trunks of most of the dendritic systems and the proximal parts of their branches lie in the dermal bones, but in their upper denser layer. The openings of the branches on the upper surface of the bone present all the various stages between the single opening and two openings about to become separate that the pores do on the external surface of the head. The number of openings on the upper surface of the bone does not, however, usually correspond with the number of external pores; for where the dermis is thick, as on the end of the nose, around the posterior nares, and along the edges of the pre-operculum, there may be one or more series of branches lying in it, entirely above or beyond the bones; and where the dermis is thin, although some of the branches pass directly through it to the external surface, others, of the creeper-like form shown in Cut 1, *k*, are continued along the outer surface of the bone in long channelled lines, the bone not yet fully inclosing them.

Course of the Canals.

In tracing the canals through the dermal bones, the method used was the following. The head of a fish was boiled a few minutes, cleaned as much as possible, and then allowed to macerate until the tissues were thoroughly softened. The different bones that contained any part of the canals of the lateral system were then separated and carefully cleaned, the outside with a brush, and the canals by forcing water through them with a pipette. They were then heated in water and injected with a blue gelatine solution, and after a short exposure to the air, to allow the gelatine to set, cleaned and put in 50 per cent alcohol. The smaller tubes of the system, that the gelatine mass had failed to penetrate, were filled by forcing with a needle little plugs of the cold injection mass into them from the openings on the surface. Finally, the bones were scraped on the inner surface below the canals, until under the microscope every branch could be distinctly traced. In bones that had been simply macerated without boiling, the canals and branches were so filled with a chalk-like deposit that they could not be successfully injected.

All the dermal bones containing any part of the canals of the lateral system are shown in Figs. 40–43, Pl. XL. They are enlarged two diameters, and all, excepting the suprascapula and supraclavicula, placed in serial order as they occur in the fish. In these figures the canals and dendritic systems lying in the dermal tissues between the frontal and nasal, and at either end of the pre-operculum, are shown, as well as all the ramifications of the osseous canals, and the openings and channelled lines on the outer surfaces of the bones. In Figs. 45, 46, and 47, Pl. XLI., three views are given of the skull, natural size, with the dermal bones in place. In Figs. 46 and 47 the canals are, for fuller illustration, shown on both sides of the head, but the dissections were made on one side only, and the perfect bilateral symmetry shown in the drawing does not exist in nature.

The arrangement of the canals and dendritic systems shown in these figures is the normal one, from which there are, however, frequent variations. There are on each side of the head the three well-known canals: the infra-orbital, supra-orbital, and operculo-mandibular, and in addition a supratemporal or occipital cross-commissure.

1. *Infra-orbital Canal.* — The infra-orbital is the main canal of the system, and is directly continuous with the lateral canal of the body. It has four parts or regions, which develop somewhat independently: an antorbital, a suborbital, a squamosal or temporal, and a post-temporal, — all continuous in the adult. The antorbital part of the canal begins at a sharp bend in the suborbital portion, immediately in front of the eye and below the posterior nasal aperture. It runs forward and downward, and partly encircles the nasal tube (which in Amia is the anterior nasal aperture), running below and in front of it, and uniting, on the top of the snout between the nasal tubes, with the corresponding canal of the opposite side of the head. This antorbital portion, which is more properly an anterior cross-commissure connecting the two main infra-orbital lines, seems to be found in some other ganoids; for Traquair (No. 18, p. 181) describes a similar connection in *Polypterus bichir*, and Leydig (No. 9, p. 249) three of them in *Chimæra monstrosa;* but it is not found in the teleostei, so far as can be judged from the descriptions I have been able to find. According to Sagemehl (No. 14, p. 36), it does not exist in the Characinidæ, nor is it found in *Amiurus catus* (No. 21, p. 265), and from my own examinations I know it is not found in *Salvelinus namaycush*, *Micropterus dolomieu*, *Esox lucius*, or *Stizostedium vitreum*. In Salvelinus, a line of organs lying wholly in the external epidermis, occupies about the position of the canal in Amia. These organs belong to the same class as the canal organs. There are several other lines on the head of Salvelinus, and corresponding ones on that of Amia.

The suborbital part of the infra-orbital part is, in the adult, connected at its anterior end, immediately in front of the posterior nasal aperture, with the supra-orbital canal. There is no direct union of the two lines here, the connection being of the nature of a commissure formed by the anastomosis of two dendritic systems, one of which is the terminal system of the suborbital, and the other the fourth regular system of the supra-orbital canal. Starting from this point, the suborbital canal runs forward and downward to a point above the anterior end of the maxillary, where it is joined by the antorbital canal or anterior commissure; it then turns sharply backward, and lying above the upper edge of the maxillary and jugal and below the

eye, it somewhat more than half encircles the orbit, extending to a point above and behind it, and a little in front of the blind upper end of the spiracular canal. The canal here turns sharply backward, and, as the squamosal or temporal portion, is continued backward and upward above the pre-opercular fold, to a point between this fold and the upper end of the opercular opening, where it gives off the supratemporal cross-commissure. The post-temporal portion lies behind this commissure, continuing at first in the line of the squamosal canal upward and backward, above the upper end of the opercular opening, and then downward and backward under the upper and posterior margin of the operculum, to the hind edge of the supraclavicula, where it joins the anterior end of the lateral canal of the body.

2. *Supra-orbital Canal.* — The supra-orbital canal begins a little median to and behind the nasal tube. It runs at first toward the median line, and then almost directly backward above the eye, ending near the hind margin of the frontal, and sending its posterior branches into the anterior part of the parietal and squamosal. Behind the eye it is deflected somewhat laterally, and anastomoses with the infra-orbital canal at the bend in that line where the suborbital portion joins the squamosal. The arrangement of the canals in the adult at this point is such that the supra-orbital has always been considered the direct continuation forward of the squamosal or temporal portion of the infra-orbital, the two together being described as the main lateral canal of the head, and the suborbital as one of its branches. The development of the canals in Amia shows conclusively that this interpretation is wrong, for the supra-orbital develops independently, its innervation is different, and it only acquires its connection with the main infra-orbital as an anastomosis after both canals have been fully inclosed.

That this independence of the supra-orbital canal is not peculiar to Amia is shown by the arrangement in the Characinidæ as given by Sagemehl (No. 14, p. 36). In these fishes the supra-orbital has, in the adult, the condition found in the larva of Amia; that is, it is separate and distinct from the main infra-orbital, broken off from it, as Sagemehl says, by the intrusion of the anterior end of the dilator operculi muscle, which has in this fish an unusual insertion on the upper sur-

face of the post-orbital process. His description of the canal in the Characinidæ shows that it agrees closely in general course and position with that of Amia, beginning in both forms at the anterior end of the nasal, median to the nasal openings, and ending at the hind margin of the frontal, where one or more branches are sent backward into the parietal. The main canal in the Characinidæ also agrees closely with that in Amia, but Sagemehl describes the suborbital part of it as a branch given off downward behind the eye, from the extreme anterior end of what he considers to be the main temporal or posterior division of the supra-orbital.

3. *Operculo-mandibular Canal.* — The operculo-mandibular canal begins at the anterior end of the lower jaw, close to the middle line of the head and close to the anterior end of the canal of the opposite side, but without any connection whatever with it. Bridge (No. 4, p. 620), Sagemehl (No. 13, p. 183), Van Wijhe (No. 19, p. 288), and Shufeldt (No. 16) all agree in stating that here the two canals are continuous; but this was not the case in any of the many specimens I have examined.

Starting here as an independent line on each side of the head, the mandibular part of the canal runs backward along the lower inner margin of the ramus of the mandible, nearly to its hind end, where it turns upward and passes out of the mandible immediately in front of and above the articular process for the symplectic. It then turns sharply backward and is continued as the opercular part of the canal upward and backward through the pre-operculum in the curved line of that bone. Leaving the bone at its upper end it passes through a narrow strip of dermis, and joins the infra-orbital canal, near the hind end of the squamosal, turning forward at the point of union. The mandibular and opercular portions of the canal develop as two distinct canals, uniting later with each other to form a continuous line and then uniting with the main infra-orbital. These later connections in Amia are not always formed in other fishes. In *Esox lucius* for example, the two portions always remain, even in the adult, separate from each other and from the infra-orbital; and in *Polypterus bichir*, *Amiurus catus*, and *Cottus gobio*, although they unite to form a continuous line, they do not unite with the main canal.

4. *Supratemporal Cross-commissure.* — The supratemporal

cross-commissure lies in the temporal region. Leaving the main infra-orbital canal in the extrascapula it runs slightly forward toward the top of the head, and meets there the end of the corresponding canal of the opposite side, thus forming a second connection between the two main lines, the first or anterior one lying on the top of the snout, as already described. These two are the only connections that are formed in Amia between the lateral systems of the opposite sides of the head.

Leaving the several canals at irregular intervals, but at definite places, are the trunks of the different peripheral canal systems, each of which is represented on the outer surface of the bone by a distinct group of openings.

Topography of the Peripheral Canal Systems.

1. *Infra-orbital Canal.* — The infra-orbital canal, which is the direct continuation of the lateral line of the body, traverses in succession the supraclavicula, suprascapula, extrascapula, squamosal, postfrontal, post- and suborbitals, lachrymal, antorbital, and ethmoid, joining in this last bone the canal of the opposite side. Beginning at this point, in the middle line of the head, the canal first runs forward, outward, and downward to the outer anterior end of the arm of the V-shaped ethmoid, giving off at about two-thirds its course through the bone a branch which runs straight forward and upward to the surface of the bone, and has there a single large opening. This branch canal represents the second peripheral system of the line, the first system having disappeared at the middle line of the head, as will be described later. It may be designated as trunk 2 (Fig. 41, Pl. XL.), and the corresponding pore or group of pores on the external surface as group 2.

Leaving the ethmoid, the main canal turns sharply backward and upward, and entering the antorbital at its extreme anterior end, runs upward and backward along the middle line of the bone for about two-thirds its length. At this point, which is approximately above the articular end of the maxillary, it turns backward and leaves the bone at its hind margin. In the antorbital the canal gives off the trunks of four peripheral systems: trunk 3 at the beginning, trunk 4 at about one-third, and trunks 5 and 6 close together at about two-thirds its course through

the bone. Trunk 3 runs forward and outward, and lies so far forward that it is not entirely inclosed in bone, leaving the canal between the ethmoid and antorbital, giving off no branches in the bone. Trunk 4 is directed downward, forward, and outward, and has a single large opening at the surface of the bone. Trunks 5 and 6 are given off almost at the same point, but on opposite sides of the canal, just before or at the horizontal bend in it. Trunk 5 is short, and is directed outward and downward. It sends one long branch forward with two single and one double opening, and one branch outward and downward which has two short branches with five openings, making in all seven single and one double opening in the system, all lying along the lower outer edge of the bone. Trunk 6 is a direct continuation upward and backward of the antorbital part of the main canal, and is comparatively long, extending from the bend in the canal to a point beyond the upper posterior margin of the bone and a little in front of the posterior nasal aperture. Here it runs directly into, and is continuous with, trunk 4 supra-orbital, the two trunks or some of their branches meeting and anastomosing, and so forming a direct connection between the two canals.

Trunk 6, infra-orbital, after leaving the antorbital bone at its hind end, enters the little strip of dermal tissue (near the lateral edge of which the posterior naris lies), which extends across the top of the head between the lachrymals, and between the frontals behind and the nasals and antorbitals in front. The canals that traverse this strip of dermis lie in a deeper, denser stratum of the corium, which corresponds in position to that of the dermal bones in other places. Trunk 4 supra-orbital lies entirely in this tissue, as does also 6 infra-orbital after leaving the antorbital bone at its upper end. This latter trunk usually sends one or more creeper-like branches forward, toward or into the hind margin of the nasal, and one or more backward, toward the median or anterior edge of the posterior nasal aperture; but these branches are given off so near the point of anastomosis that it is often difficult to determine to which one of the systems they belong. In the two systems combined, in the specimen used for illustration, there were on one side of the head twenty-six pores, and on the other twenty-seven, three on one side and five on the other being in the nasal.

The anastomosis of these two peripheral systems is not formed until the fish is well advanced in age. In the large 15-month specimen shown in Fig. 17, it is just forming. It is brought about in the following way: trunk 4 supra-orbital, which leaves its canal immediately in front of the frontal, runs forward and laterally until it reaches a point median to the anterior edge of the posterior nasal aperture. Here it turns backward, and runs toward the anterior edge of the frontal, often extending beyond this edge onto the upper surface of the bone. Trunk 6, infra-orbital, lies almost exactly in the line of the main part of trunk 4, supra-orbital, the two trunks and their system of pores and branches growing directly toward each other until either the trunks or some of their branches come squarely together and unite at or near the bend in trunk 4, enlargements being usually formed at the points of union. A remnant of the dividing wall remains, indicating the line where the two systems came together. *This is the only place in the entire lateral system of Amia where an anastomosis below the surface occurs;* for, even where terminal branches of the same or neighboring systems are united below the surface, as shown in Fig. 40, Pl. XL., *ig*^{9}, the union, so far as I have been able to determine, is always first formed at the surface by the fusion of two pores in a manner to be fully described in treating of the development of the system.

Leaving the antorbital at its hind edge, at about two-thirds the length of the bone, the main canal enters the upper anterior edge of the lachrymal, and, running backward along its middle line, gives off the trunks of three peripheral systems, — trunk 7, immediately on entering the bone, trunk 8, about half-way through it, and trunk 9, just before leaving it. All these trunks run outward, downward, and forward. Trunk 7, which is short, lies just above a small notch in the lower anterior corner of the lachrymal. Its system has three large openings along the upper edge of the notch, and five along a slender branch directed backward from it, making eight in all.

The openings of the next two systems, 8 and 9, are arranged along the entire lower, lateral edge of the lachrymal. No. 8 has three double and two single openings, and No. 9 two double and seven single ones. One of the double openings in this last system is formed by the anastomosis of two branches at their outer ends, an instance of the fusion of two pores in adult life

already referred to. The posterior branch of this system is continued as a groove onto the outer surface of the first suborbital.

Leaving the lachrymal, the canal passes through the middle of the two suborbitals, and enters the lower postorbital near its lower anterior angle. Running upward and backward in this bone, to about one-quarter its length, the canal turns directly upward, traverses the rest of the bone, and enters the upper postorbital at the anterior quarter of its lower edge. Turning somewhat forward here, it passes through this bone, turning directly upward again and then backward, just as it leaves it, to enter the postfrontal.

In its course through the sub- and postorbitals, the canal gives off the trunks of seven peripheral systems. The first one, trunk 10, leaves the main canal near the hind end of the first suborbital. Dividing immediately, it sends one branch forward, with five large openings near the lower edge of the bone, and one backward, ending in a groove on the anterior end of the outer surface of the second suborbital, making six openings in all, three of which at least are double. Trunk 11 is given off upward and outward near the hind end of the second suborbital. It sends one branch forward along the outer edge of this bone toward the end of the branch from trunk 10, and another backward into the lower postorbital, the two branches having sixteen openings in all, five, three of which are double, being in the suborbital, and eleven single ones in the postorbital. Trunk 12 leaves the canal where it turns directly upward at about the middle of its course through the lower postorbital. It is directed downward and backward, and gives off several branches, each of which divides again one or more times, the longer branches lying mostly parallel to the main trunk. It has in all thirty-seven openings, which lie in a group a little in front of and below the middle point of the bone. Trunk 13 is short, and is given off just as the main canal enters the upper postorbital. It divides immediately, sending one branch, with eight openings, downward and backward into the lower postorbital, and another, with twelve openings, upward and backward into the upper postorbital, making twenty openings in this system. Trunk 14 is given off at about three-quarters of the course of the canal through the upper postorbital, the bone here being

very thick, and is directed backward and outward. It sends a large branch backward to about the middle of the bone, and another forward toward the eye, in front of the main canal, both of them branching several times, and having in all thirty-seven openings, all lying in front of the middle point of the bone, and extending almost to its extreme anterior edge.

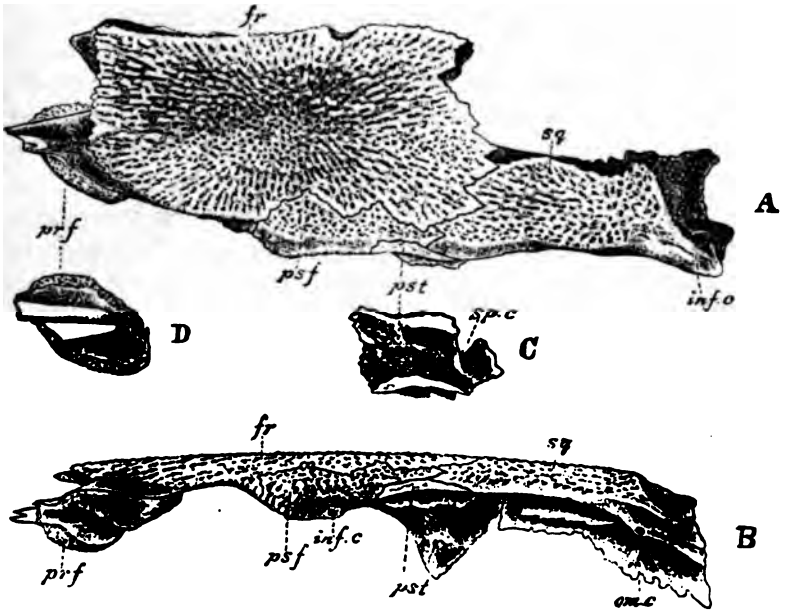
The canal, after leaving the upper postorbital, enters the postfrontal, where it has a curved course, turning gradually backward till it reaches the median edge of the bone at about its middle point. Here it turns directly backward, and, running between the frontal and postfrontal, enters the squamosal at about the middle of its anterior end. It traverses this bone from end to end, running directly backward with a slight lateral bend near the hind end, where it is joined by the opercular canal.

In the postfrontal, the canal lies entirely in what Sagemehl (No. 13, pp. 184 and 185) considers merely the outer, denser, and harder part of the primary ossification of the postorbital process. This ossification, which is traversed by a canal of the lateral system, and the prefrontal, which is not, are both considered by him as exceptional instances of primary ossifications that have acquired secondarily the surface characteristics of true dermal bones. He calls attention to the earlier work of Bridge (No. 4, p. 607), who describes each of these bones as having an outer dermal component wholly separate from the underlying primary ossification; but he nevertheless strongly asserts that this separation can only be made by fracture.

In the several specimens which I have examined with special reference to this point, I have always found the prefrontal a single bone and the postfrontal in two parts. The prefrontal (Cut 2, *prf*) lies under the outer anterior corner of the frontal, projecting slightly beyond it, but in no place rising above the level of its under surface. The projecting edge is continuous with the edge of the frontal, which in this place is bevelled, and, although roughened, it has neither the character nor appearance of the outer surface of the dermal bones. In the unprepared head it is covered by thick dermis, and its roughened edge gives attachment to strong membranes. It lies deep and is not traversed by the main cranial canals or any of their branches.

The dermal portion of the postfrontal (Cut 2, *psf*) is a small

bone, somewhat triangular in shape, exactly filling a large notch extending from the middle of the lateral edge of the frontal to the hind edge of the bone. Its small posterior end usually fits into a notch in the anterior end of the squamosal, which overlaps somewhat its lateral edge. It rests directly upon the deeper postorbital ossification, and is so closely connected with it, that in attempting to remove it in fresh specimens, one of the bones is usually broken, and a fractured surface obtained; but in skeletons properly prepared, — by maceration or by boiling, — the



Cut 2. — *A*, top view of frontal, postfrontal, prefrontal, and squamosal bones, showing the postorbital ossification in place; *B*, side view of same; *C*, top view of postorbital ossification after removing the dermal bones; *D*, top view of prefrontal after removing the frontal; *fr*, frontal; *inf. c*, infra-orbital canal; *om. c*, operculo-mandibular canal; *prf*, prefrontal; *psf*, postfrontal; *pst*, postorbital ossification; *spc*, spiracular canal; *sq*, squamosal.

two bones are easily parted, leaving a clean and perfect surface of separation. The postfrontal projects beyond the postorbital ossification in front, and forms part of the roof of the orbit. The lateral edge of this part of the bone is thickened, frequently having a rib-like projection along its under surface, as if the edge of the bone had been turned down and a little under. The upper corner of this thickened edge and the corners of

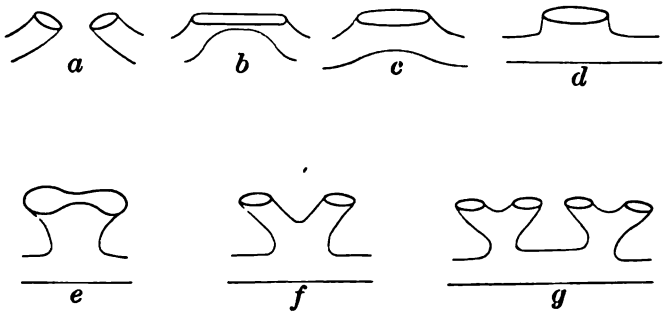
the bones immediately behind it are slightly bevelled, thus forming a shelving surface which looks upward and outward, and, when the cheeks are distended, serves as an articular surface for the overlapping edge of the upper postorbital. This lateral rib or thickening only extends one-half the length of the bone, which behind it is much smaller and narrower, the lateral edge and under surface being cut away by the postorbital process, a small portion of which here comes to the level of the outer surface of the dermal bones (Cut 2).

The postorbital ossification has roughly the shape of an inverted pyramid, one edge of which projects laterally and forms the hind boundary of the orbit. The upper outer angle of the ossification expands into an elongate cap-like piece, which overhangs the pyramid in front, behind, and laterally. Its outer surface is divided into two portions by a strong longitudinal line, which is continuous in front with the lower outer edge of the postfrontal, and behind with the corresponding edge of the squamosal. The part above this line is the small portion that forms a part of the external surface of the dermal bones, and it has in every particular the characteristic appearance of these bones. The part below the line lies at a deeper level and gives attachment to portions of the *levator arcus palatini* and *adductor mandibulæ* muscles. The line separating these two surfaces is sharp and strong, while that separating the upper surface from the dermal postfrontal is faint and indistinct, and might easily be overlooked.

The postorbital ossification gives support on its upper surface to the frontal and squamosal as well as to the postfrontal, but neither of these bones are closely attached to it. The squamosal projects slightly under the frontal and postfrontal, and separates the main lateral canal from the spiracular canal, which opens widely on the upper surface of the skull immediately below it. The spiracular canal has been fully described by Sagemehl (No. 13, p. 200) and by Wright (No. 20, p. 492).

The infra-orbital canal enters the postfrontal in front of the lateral edge of the postorbital ossification (Cut 2, *inf. c.*), and no branch is given off in its course through it. At the median edge of the bone it forms an anastomosis with the supra-orbital canal, and a double system is given off; that is, one formed by the complete fusion of two systems, one belonging to each of

two anastomosing lines. There are seven such systems on the head of Amia, all of them essentially similar. Their pores multiply exactly as do those of a simple system, but the double trunk increases greatly in width along the canal, and the primary division of it is so deep that the trunk becomes practically a part of the canal (Cut 3, *e. f. g*), its two primary branches appearing as the trunks of separate systems. This is the condition found at the point of anastomosis of the infra-orbital and supra-orbital canals. The two systems that have fused here are Nos. 15 infra-orbital and 7 supra-orbital, and that part of the main canal lying between the frontal and postfrontal and extending as far as the anterior edge of the squamosal is in reality the



Cut 3. — Diagrammatic representation of the formation of a double pore and system: *a*, *b*, and *c*, two pores approaching and fusing; *d*, double pore and tube; *e* and *f*, the same, undergoing its first division; *g*, double system after second division of pore and tube.

trunk of the double system. The anterior primary branch of this system (Fig. 40. Pl. XL.) runs forward and outward into the postfrontal, sending one branch medianward into the lateral edge of the frontal, and having thirty openings in all, three of them in the frontal. The other issues at the anterior edge of the squamosal, sending one branch forward and another backward, with ten openings in the postfrontal and thirteen in the squamosal.

Trunk 16, the next regular one, is given off in the squamosal beyond the middle line of the bone, and is a short trunk directed laterally. It sends one long branch forward, overlapping the posterior branch of trunk 15, and a shorter one backward. It has twenty-nine openings, all lying near the lateral edge of the bone. Behind this trunk the main infra-orbital is joined by the

operculo-mandibular canal which comes up through the pre-operculum. At the point of union a double system is formed by the fusion of system 17 infra-orbital with 17 operculo-mandibular; but the trunk of this system has been pushed out of its proper place down into the opercular line, and lies with all its branches in the dermal tissue between the upper end of the pre-operculum and the lateral edge of the squamosal. Its primary branches are not so widely separated as those of the double trunk 15–7. They are directed one forward and the other backward, with all their branches running downward and with eighteen openings in all.

Leaving the squamosal at its hind end on the short shelving surface which is overlapped by the extrascapula, the main canal passes through a strongly raised portion on the under surface of the latter. It then traverses the suprascapula, entering it on its upper surface near its lateral edge, where it is overlapped by the extrascapula, and leaving it on its under surface, where it, in turn, overlaps the supraclavicula. Entering the supraclavicula on its upper surface at its upper end, it passes downward and backward through this bone, leaving it on its under surface to enter the first scale of the lateral line of the body.

The extrascapula overlaps the squamosal in front and the suprascapula behind, so that the canal only passes through the middle third of the bone, giving off trunk 18, with thirty-six openings, near its entrance, and trunk 19, with twenty-two openings, near its exit from the bone. Trunk 20 is given off in the suprascapula just as the canal leaves the bone. It runs backward and outward, and has thirty-nine openings, some of them double or triple. Trunk 21, given off soon after the canal enters the supraclavicula, runs backward, and, branching once, has two openings only at the hind edge of the bone. Trunk 22, the last one of the cranial system, is also trunk 1 of the lateral line. The supraclavicula overlaps the first scale of the lateral line, and the double trunk 22–1 is given off at the point where the main canal leaves the supraclavicula and turns inward to enter the scale. It is a long, open channel on the under surface of the bone, running downward and backward as a direct continuation of the main canal, and having a single large opening at the hind edge of the bone.

2. *Lateral Line of the Body.* — The first scale of the lateral line (Fig. 44, Pl. XL.) is always an irregular one. It is smaller than those immediately following it, much thickened, and roughly triangular in shape. It extends under the supraclavicula and lies in the direction of trunk 22–1, at an angle to the following scales of the line. The lateral canal enters it near its front edge, and leaves it on its inner surface, entering the next scale on its outer surface, and leaving it on the inner after traversing approximately its middle third. It passes in the same way through the other scales of the line normally, giving off in each a peripheral canal system, similar to those found on the head. The trunk of each of these systems is given off at the extreme posterior end of the section of canal contained in the scale to which the system belongs. It lies in the direction of the canal and soon branches dichotomously, sending one branch upward and one downward, each with one or more openings on the outer surface of the scale. These openings lie near the hind edge of the scale, and are approximately concentric with it. The system of the first scale of the line is very irregular. It always has fewer surface openings than that of the next following scale, or no openings at all; the trunk is present, but in a more or less aborted condition.

3. *Supratemporal Cross-commissure.* — The supratemporal cross-commissure is given off medianward from the main canal, between trunks 18 and 19, in the extrascapula; it traverses the length of this bone in about its middle line and joins, on the top of the head, the corresponding canal of the other side. In the full commissure there are two peripheral systems on each side and a double one in the middle. The two primary branches of this median system have become so widely separated in the adult that there are apparently three systems on each side of the head, the trunks of all of which run backward and laterally, with most of their branches directed backward and medianward. The median one of these three systems, although only a half-system, may be called No. 1, and it has in the specimen figured eight osseous openings. The next system, No. 2, has nineteen, and the lateral one, No. 3, twenty-five.

4. *Supra-orbital Line.* — The supra-orbital canal begins near the anterior end of the nasal. It runs for a short distance backward and medianward, and then, turning sharply backward,

continues in about the middle line of the bone to its hind edge, and then passing through the strip of dermal tissue, lying between the frontal and nasal, enters the frontal at about the middle of its anterior edge. It traverses this bone along its middle line for about half its length and then curves gradually outward until it reaches the lateral edge of the bone, where it meets and anastomoses with the infra-orbital canal, as already described. Leaving this canal immediately, it runs medianward and backward to the hind edge of the frontal, and then into the anterior and lateral part of the parietal, where it comes to the surface and ends.

Trunk 1 of this line leaves the canal at its extreme anterior end, and, running forward and laterally, has two openings at the outer edge of the nasal, immediately behind the notch made in this bone for the passage of the anterior naris. Trunk 2 leaves the canal exactly at the bend, and runs forward toward the anterior edge of the nasal, where it branches regularly, and has four openings on the surface of the bone, three single and one double. Trunk 3, given off near the middle of the bone, runs medianward and forward, and has eight single and six double openings arranged along the median edge of the bone. Trunk 4 is given off nearly opposite the posterior nasal aperture from that part of the canal lying in the dermal tissue between the nasal and frontal. It runs forward and outward, turning backward along the median edge of the nasal aperture, and anastomosing with trunk 6 infra-orbital, as already described. Trunk 5 is given off laterally at about one-third the length of the frontal, and trunk 6 medianward at about the middle of it: both are short and stout. No. 5 sends a long branch backward, overlapping the anterior branches of No. 6, and another forward almost to the anterior edge of the frontal. In front of this last branch, and also in front of several of the smaller branches, there are deeply channelled lines in which the epidermal canals of the system are continued onward along the upper surface of the bone, partly imbedded in it, and extending in some cases into the strip of tissue in front of it, reaching even to the hind edge of the posterior nasal aperture. System 5 has twenty single openings and eleven double or channelled ones, and system 6, thirty-three single and ten double or triple ones. Trunk 8 is a direct continuation backward of that

part of the canal lying beyond the point of its anastomosis with the infra-orbital line; two of its branches lie in the frontal, both directed backward and laterally, one reaching to the extreme hind edge of the bone, and the other sending a short branch beyond this bone into the squamosal. The two branches have six single and three double openings in the frontal and two in the squamosal. A third and principal branch is sent backward, directly in the line of the trunk, into the parietal, near its anterior and lateral corner. It runs straight backward in this bone, sending six branches to the surface, making seventeen openings in the entire system.

5. *Operculo-mandibular Line.* — Close to the anterior end of each ramus of the mandible there is a single large opening which marks the beginning of the mandibular line. The tube from this opening leads backward and outward laterally into the anterior end of the mandibular canal, which, starting here, runs backward along the lower inner edge of the dentary. Leaving this bone, it enters the angular, and, turning upward near its hind end, passes out of it, and out of the upper surface of the mandible immediately in front of and above the articular process for the sympletic. It then turns sharply backward, and passing through the thick dermis between the angular and preoperculum, enters this last bone on the dorsal surface of its lower anterior end. It passes through the entire length of this bone, lying near its inner deeper edge, and then passing again through a strip of dermis it enters the squamosal and unites with the infra-orbital canal.

Along the mandibular part of the canal there are ten and a half peripheral systems, seven in the dentary and three and a half in the angular, most of them branching several times. Trunk 1 is a direct continuation forward of the main canal, which begins here, and has no connection whatever with the corresponding canal on the other side of the head. It has a large single opening at the front end of the dentary near the symphysis. Trunks 1 to 10 lie along the anterior horizontal part of the canal. No. 10 leaves it at the point where it turns upward near the hind end of the angular, and has one branch running straight backward as a direct continuation of the main canal. In these ten systems there are seventy-four openings, twenty-eight of them plainly double.

System II. is a double one formed at the point where the mandibular and opercular parts of the canal unite. Its primary branches are widely separated, one of them lying in the angular, near the upper end of the bone, and the other in the thick dermis between the angular and pre-operculum. The former has twenty-eight openings, eighteen in the angular and two in the supra-angular; and the latter, seven, all in the dermis, making twenty-seven in all for the entire system.

In the opercular part of the canal, the trunks of five peripheral systems are given off, Nos. 12 to 16, all of them running outward, and backward or downward, toward the outer edge of the bone, where each has several large irregular openings, approximately thirty-four in all. Trunk 17, the last one of the line, has united with 17 infra-orbital, as already described, to form a double trunk and system which lies wholly in the dermis between the pre-operculum and squamosal.

The mandibular canal in Micropterus dolomeus and in Salvelinus namaycush passes through the articular, and not through the angular, as in Amia and in Polypterus (No. 18, p. 182). In those two teleosts the angular is a small bone lying below or behind the articular, which is large and has the same position relative to the dentary that the angular has in the two ganoids. The articular in Polypterus is small, and lies below and behind the angular; and in Amia, what Bridge has called ossicle holds a corresponding position. This ossicle is, according to him, formed by the ossification of the hind end of Meckle's cartilage. It is covered by a small ganoid plate; and Bridge suggests that it may represent, at least in part, the articular of teleosts. But neither it nor the overlying dermal plate is traversed by a lateral canal, while the angular is. This last bone in the ganoids has doubtless been so called because it is entirely dermal, agreeing in this respect with the angular in teleosts, and differing from the articular, which has been supposed to be always pre-formed in cartilage. As the teleostean articular is in some forms traversed by a lateral canal, this distinction does not hold good, and the names now used for the bones in the ganoids should probably be changed.

6. *Summary.*—In this specimen, which is strictly a normal one, there are in all *ninety-three peripheral canal-systems, forty-six on each side of the head, and a median one in the supratemporal*

cross-commissure. This median system is a double one (Cut 3, *g.*), *and there are on each side of the head three other similar systems, making seven in all.* One is formed by the fusion of systems 15 infra-orbital and 7 supra-orbital; a second one by the fusion of 17 infra-orbital and 17 operculo-mandibular, and the third by the union of the two portions of the operculo-mandibular canal. This last system, being formed in the line of its canal, is called No. 11 of that line. The other two being formed at the points of anastomosis of two different lines, have each been given a double number which indicates the position of the system on each of the lines to which it belongs. Counting it this way, there are three peripheral systems along the supratemporal cross-commissure, eight along the supra-orbital line, seventeen along the operculo-mandibular, and twenty-one along the infra-orbital; but as a median double system has disappeared at the point where the two infra-orbital lines unite on the top of the snout, there are properly twenty-two systems along this line, seventeen of them up to the point where it is joined by the operculo-mandibular.

Surface Pores.

The peripheral canal systems are represented on the surface of the head by more or less distinct groups of pores. The number of pores in some of these groups can be easily determined by surface examination; but in many cases several groups are so run together that only the general position of each group and the total number of pores in the series can be ascertained.

For the following description three specimens were used: two males, one 17 in. and the other 20½ in. in length, and a female 27 in. long. The number of pores given in the different groups, unless otherwise specified, applies only to the left side of the head, a comparison being made in every case with the number of openings in the skeleton. The arrangement of the surface pores in the larger male is shown in Figs. 20, 21, and 22, Pl. XXXVI.

1. *Infra-orbital Line.* — The first group of the infra-orbital line, group 2, lies near the base of the nasal tube, a little in front of and median to it. It has usually one or two pores

only, arranged, where there are two, across the top of the snout. In the 17-inch specimen, which seemed an exceptional one in many ways, there were three pores in this group on each side of the head, the third pore lying a little in front of, and lateral to, the two regular ones. In no other specimen were more than two pores found. In the skull there was but one opening in the ethmoid corresponding to this group, showing that the division of the trunk lies in the dermis entirely above the bone.

Group 3 lies near the edge of the upper lip, below and in front of the nasal tube, and has but one pore, or two lying parallel to the edge of the lip. As the trunk of this system issues in the dermis between the ethmoid and antorbital, there is no corresponding opening in the skull.

Group 4 lies near the edge of the upper lip, lateral to and below the nasal tube, and usually has two pores in the adult. In the 17-inch male there were two pores in the group on each side of the head; in the 20½-inch male, two on one side, and four, arranged in a square, on the other; and in the 27-inch female, three, lying in a line parallel to the edge of the lip. In the skull there was a single opening only.

Group 5 lies back of and lateral to the nasal tube, and below the dermal crease which extends from the base of the tube toward the posterior nasal aperture. The number of pores in this group varies, as does also their arrangement, and they are nearly, if not quite, continuous with those of group 7. In the 17-inch specimen there were eight pores in the group; in the 20½-inch one, nine; and in the 27-inch one, nineteen. One or more of the anterior pores of the group lie close to the dermal crease before mentioned, and directly opposite the pores of group 1, supra-orbital. In the skull there were eight openings in this system.

Group 6 belongs in position to the supra-orbital line, and will be described with group 4 of that line, with which it is continuous.

Group 7 lies behind, and lateral to, group 5, considerably below the posterior nasal aperture, and immediately above group 8.

Groups 8 to 11 lie along the upper edge of a deep furrow which separates the maxilla from the side of the head. The maxilla, when the mouth is closed, shuts under the overhanging

edges of the lachrymal and first suborbital, and over the lower edge of the second suborbital and the lower anterior corner of the lower postorbital, fitting into a depression on the outer surface of these two bones. The lower edges of the lachrymal and first suborbital, and the upper edge of this depression from the upper edge of the furrow, which is continued a short distance downward and backward behind the maxilla along the hind edge of the mandible. In young specimens the edge of this furrow, which may be called the *supramaxillary furrow*, is straight, and the pores of groups 8 to 11 are closely arranged in a line along it; but in the adult it is strongly ogee-shaped, and many pores may lie above the marginal row, especially immediately below or just in front of the eye. Group 12, which is usually continuous with group 11, lies immediately behind the maxilla, near the lower edge of the lower postorbital, and often extending beyond it. It is usually continuous with groups 13 and 14, which lie above and before it, directly behind the eye, superficial to the postorbitals and below the lateral edges of the postfrontal and squamosal. In these eight groups, Nos. 7 to 14 inclusive, there were in the 17-inch specimen one hundred and two pores, and in the 27-inch one, three hundred and thirty-three. In the 20½-inch male, either system 13 or 14 was wanting (probably No. 13), a condition frequently found, and there were accordingly only one hundred and one pores in groups 7 to 14, while in the skull, where the number of groups was normal, there were one hundred and forty-nine openings.

The pores of the double system, infra-orbital 15, supra-orbital 7, and those of group 16 infra-orbital, form a continuous line, extending from immediately above and behind the eye, nearly to the front edge of the extrascapula, which edge lies in line with the upper end of the pre-opercular fold. Some of the pores of these two groups extend laterally beyond the edges of the postfrontal and squamosal. In the 17-inch specimen there were eighty-nine pores in the two groups; in the 20½-inch one, seventy-eight; and in the 27-inch one, two hundred and eighty-eight. In the skull there were eighty-two openings.

Groups 18 and 19, and group 3 of the supratemporal commissure, form one large surface group. Groups 19 and 20, and 20 and 21, are also more or less continuous, but easily distinguishable, as seen in the figures. Groups 18 and 19 infra-orbital

and the three groups of the supratemporal line all lie superficial to the extrascapula. They extend slightly beyond its margins, and form, with the same groups on the other side of the head, a nearly continuous series which lies behind the line of the pre-opercular fold and in front of the first row of scales. In the 17-inch specimen there were ninety-four pores in these five groups on one side of the head; in the 20½-inch one, one hundred and two; and in the 27-inch one, two hundred and fourteen. In the skull there were one hundred and ten openings.

Group 20 lies on a fleshy pad above, and immediately in front of, the upper end of the opercular opening, behind the extrascapula and opposite the first two or three scales behind that bone.

Group 21 is much smaller than No. 20, and lies on a similar but smaller pad above and behind the upper end of the opercular opening, above the upper edge of the supraclavicula and opposite the third and fourth, fourth and fifth, or fourth, fifth, and sixth scales, behind the extrascapula. The pores of this group often extend onto the bases of the scales, but when this occurs, the canals leading to them lie entirely in the dermis or epidermis, not entering the bony part of the scale at all. There were in groups 20 and 21, in the 17-inch specimen, thirty-nine pores; in the 20½-inch one, fifty; in the 27-inch one, ninety-one; and in the skull forty-one openings.

Groups 20 and 21 and those found on the first five scales of the lateral line in the 27-inch specimen are shown in Fig. 39, Pl. XXXIX. The hind edge of the gill cover is cut off in order to show the position of the supraclavicula and the arrangement of the scales immediately behind it. In this specimen, the pores of group 21 extended onto the base of the sixth scale, counting always from the hind edge of the extrascapula, and the lateral line began on the eighth. In the 17 and 20½ inch ones, group 21 only extended to the level of the fifth scale; and the lateral line began on the seventh.

2. *Lateral Line of the Body.*—The first scale of the lateral line is always irregular, and without the thin portion which extends beyond the bone in the other scales, and which gives them their rounded outline. Between it and the hind edge of the supraclavicula there is a single large opening (Fig. 39, Pl.

XL., p. 22, *i*, *ll*), which is the undivided original double pore formed by the fusion of the posterior peripheral system of the head with the anterior one of the lateral line. Although compressed and flattened and hidden from view under an overhanging fold of dermis, this pore is the largest one in the entire lateral system of Amia.

The peripheral system of the first scale is always more or less aborted. In the 27-inch specimen it had but two pores on one side of the body and four on the other, and in the 17 and 20½ inch specimens but one pore on each side. In several other specimens there were no pores at all in this system, the scale projected but little beyond the hind edge of the supraclavicula, the end of it being cut squarely off across the line of the canal so that the exposed portion was triangular in shape, with a straight edge behind.

There were, in the several specimens in which they were counted, sixty-seven or sixty-eight full scales in the lateral line. In the second scale of the line there were, in the 17-inch specimen, seven openings; in the third, six; and in the fourth, seven. In the 27-inch one (Fig. 39) there were eight in the second scale, twelve in the third, and eleven in the fourth. In the following scales, for about half the length of the line, the peripheral systems are fairly constant and regular; but behind that there is great irregularity, some of the scales, and often several in succession, having no pores at all, and nearly all of them having a much smaller number than those in the first half of the line. Toward the tail there are usually but one or two pores in a scale (Fig 3, b, Pl. XXX.), and the development here is often so greatly arrested that the lateral canal, through one or more scales, is an open channel.

Behind the last full scale of the line the canal turns slightly downward, and enters the tail fin between two of its rays. It then runs straight backward about three-fourths the length of the fin, and ends in a single terminal pore, which is usually closed secondarily. Along this part of the canal there is only a single row of pores, those toward the end of the line being small, and often closed.

3. *Supra-orbital Line.* — Group 1 of the supra-orbital line lies near the base of the nasal tube, close to the dorsal edge of the dermal crease, which extends backward from it. There are

usually only one or two pores in this group; but in the 27-inch specimen there were six on one side and five on the other, all lying along the edge of the crease. As already stated, this group lies close to group 5 infra-orbital, the two being separated by the crease. There were two openings in the nasal bone corresponding to this group.

Group 2 has usually four pores, which form a slightly curved line, extending backward and medianward from the anterior edge of the nasal tube, and lying nearly in the line of the hind edge of the ethmoid. The group is a prominent one, and is most regular and constant in shape and position. In the 27-inch specimen it contained seven pores on each side of the head, all arranged in line as usual; but on the left side the median pore of the group, which approached closely the anterior pore of group 3, was dividing at right angles to the line of the group, the new pore lying in front of the line of the rest of the pores. In the 17-inch specimen the lateral pore of the group, on the right side, had undergone a complete division at right angles to the line of the group. These two instances were the only ones noted of a pore lying out of the regular line.

Group 3 lies near the middle line of the head, directly above the nasal sack. In the 17-inch specimen it had nineteen pores; in the 20½-inch one, twenty-four; and in the 27-inch one a still greater number; but in this specimen the group was so continuous with groups 4 supra-orbital and 6 infra-orbital that the exact number of pores in each could not be determined.

The double group, 4 supra-orbital and 6 infra-orbital, lies close to the posterior naris. A part of the pores lie in a half-circle along the median edge of the aperture, and the rest of them form two groups, one lying in front of and median to the aperture, and the other behind and median to it, or directly behind it. This last group belongs entirely to system 4 supra-orbital, and the other entirely to system 6 infra-orbital; while the half circle of pores belongs partly to each of these systems. The group is usually continuous with group 5 supra-orbital. In the 17-inch specimen it had twenty-eight pores; in the 20½-inch one, twenty-four; and in the 27-inch one, a much larger number, but it was so continuous with groups 3 and 5 that the number of pores could not be determined. The two systems lie almost entirely in the dermis, so that in the skull there were only five

openings, all in the nasal, and all belonging to group 6 infra-orbital.

Groups 5 and 6 are almost always continuous, both lying between the eyes on top of the head, No. 5 almost directly behind the posterior nasal aperture, and No. 6 much nearer the middle line of the head, and extending somewhat behind the eye. In the 17-inch specimen there were in these two groups one hundred and nine pores; in the 20½-inch one, one hundred and sixteen, and in the skull eighty-two openings. In the 27-inch specimen these groups were continuous with 3 and 4 supra-orbital and 6 infra-orbital. The total number of pores in the five groups in this specimen was three hundred and fifty-four; in the 17-inch one, one hundred and fifty-six, and in the 20½-inch one, one hundred and seventy-four.

Group 8 lies behind group 6, not so near the middle line of the head, and about half way between that group and the supra-temporal cross-commissure. It had in the 17-inch specimen twenty-nine pores; in the 20½-inch one, thirty-two; in the 27-inch one, ninety-three; and in the skull, seventeen openings.

4. *Operculo-mandibular Line.* — Group 1 of the operculo-mandibular line in all the numerous specimens examined, excepting only the unusually large 27-inch one, had only a single large pore belonging to it; the two pores, one on each side, lying directly in front of the gular plate, near the tip of the lower jaw and close to its middle line. In the 27-inch specimen there were two pores on each side of the head, lying in a line transverse to the direction of the trunk of the system as seen from below.

The pores of group 2 and those of the succeeding groups to No. 10 are arranged in regular lines, approximately parallel to the inner edge of the mandible, but the lines of the different groups are broken, and overlap, or are continuous with each other, so that the number of pores belonging to each cannot be determined. In groups 1 to 10 inclusive, in the 17-inch specimen, there were sixty-six pores; in the 20½-inch one, seventy-two; and in the 27-inch one, one hundred and twenty-five. In the skull there were seventy-four openings, many of them double.

Group 11 lies at the hind end of the mandible, in front of and above group 10, and about half way between the maxilla and the lower end of the pre-opercular fold. It lies on both sides

of the posterior prolongation of the supramaxillary furrow. The part below the furrow lies superficial to the angular element of the mandible, and is much larger than the other part which lies wholly in the dermis. In the 17-inch specimen there were sixteen pores in this group, thirteen of them in the lower portion of it; in the 20½-inch one, twenty-four, eighteen below the furrow; and in the 27-inch one, sixty-four, with fifty-eight below the furrow. In the skull there were twenty-seven openings in the angular and supra-angular, corresponding to the lower portion of this group.

Groups 12 to 17 extend from the lower end of the pre-opercular fold almost to the lateral edge of the dermal bones of the top of the head. The pre-operculum lies just in front of the surface fold, and the pores of the different groups lie mostly in lines transverse to and extending on both sides of it. Some of them extend to the very edge of the fold, and others, at the upper end of the series, reach onto the surface of the upper postorbital. In this series of groups, in the 17-inch specimen there were one-hundred and fifty-two pores; in the 20½-inch one, one hundred and fifty-five; and in the 27-inch one, two hundred and five; while in the skull there were only eighty-four large and irregular openings, showing that the branches of the different systems lie mostly in the dermis.

The total number of pores on one-half of the head of the 17-inch specimen was seven hundred and sixty-two; of the 20½-inch one, seven hundred and twelve; and of the 27-inch one, eighteen hundred and thirty-one. Other adult specimens examined had intermediate numbers, showing that the pores continue to divide, the canals leading to them increasing correspondingly in number and extent, up to a late period, if not throughout life.

II. POSTLARVAL FORMS.

1. Primary Pores.

As all the pores and branches of the peripheral canal-systems arise by the repeated dichotomous division of previously existing pores and branches, it is evident that at some stage of growth each system must have been represented by a single

primary pore with a single unbranching tube leading to it from one of the central canals. This condition is found in fishes about one month old, or from 40 to 60 millimetres long; but as the different systems pass through it at slightly different times, no single specimen or age fully represents it.

There are normally at this stage ninety-three primary pores and tubes on the entire head, — forty-six on each side and a median one in the supratemporal cross-commissure. This median pore is the last one developed, and its formation marks the end of a first period, in which the canals and the primary tubes and pores are developed, and the beginning of a second and last in which the tubes and pores begin the dividing, shifting, and multiplying which result in the complicated arrangements found in the adult. Fig. 49, Pl. XLII., is a diagrammatic representation of this stage, showing the course of the canals and the position of the primary pores and tubes. Fig. 13, Pl. XXXIV., shows the arrangement of the pores on the head of a fish 30½ millimetres long, in which the lateral system is in a somewhat earlier stage of development; and Figs. 14, 15, and 16, Pl. XXXV., that on the head of a fish 78 millimetres long, in a more advanced condition.

At the stage represented in the diagram, pores 1 and 2 supra-orbital, and 2, 3, 4, and 5 infra-orbital, are arranged nearly in a circle around the nasal tube, No. 5 infra-orbital lying somewhat out of the circle, directly in line with pores 1 and 2 supra-orbital in front, and 7 and 8 infra-orbital behind. A dermal depression separates pores 1 supra-orbital and 5 infra-orbital as in the adult. Pore 8 infra-orbital lies in a well-marked corner formed by the anterior end of the supramaxillary furrow, which turns sharply upward in a curved line. Pores 9 to 12 lie below the eye, forming with No. 8 a straight line extending directly backward. Pores 13 and 14 lie behind the eye, and above and behind it is the double pore, 15 infra-orbital and 7 supra-orbital, which, in the 67½-millimetre specimen has undergone its first division. Pore 16 is in process of division in this specimen, lying about mid-way between the double pores, 15–7 and 17–17, formed at the point where the infra-orbital and operculo-mandibular canals unite. Then follow pores 18 and 19 as a pair a little in front of the upper end of the opercular opening, and pores 20, 21, and 22–1 above this opening.

Pore 3 of the supra-orbital line and the corresponding one of the opposite side form a prominent pair about half way between the nasal apertures. Pores 6 infra-orbital and 4 supra-orbital lie close together near the posterior nasal aperture, No. 6 in front of, and No. 4 median to, it. No. 5 supra-orbital lies immediately behind No. 4, about on a level with the anterior edge of the eye; No. 6 nearer the middle line on the top of the head, between the eyes; and No. 8 behind and median to the double pore 15–7.

Pores 1 to 10 of the operculo-mandibular line lie along the lower edge of the jaw, No. 1 markedly in front of the curved line of the others. No. 11 lies almost directly above No. 10, and has in the 67½-millimetre specimen undergone its first division, the two secondary pores lying, as in the adult, one on either side of the end of the supramaxillary furrow. Pores 12 to 16 lie along the edge of the pre-operculum, Nos. 13 and 14 already double in the larger specimen.

In the supratemporal cross-commissure there are two pores on either side, and one in the middle line of the head.

The central canals at this age are inclosed in thin, bony tubes which in certain places, as in the suborbital series (Cut 9), represent the entire bone of the adult. In others, as in the squamosal and frontal, the tube lies along the edge or toward the middle of a thin, bony plate of the same thickness as the wall of the tube, and the tube and plate together form the bone. In young larvæ, where the bones are just beginning to develop, they are represented by short, semi-cylindrical pieces lying immediately below each organ. At this stage they correspond to the short, bony scales which, according to Bodenstein (No. 3, p. 131), partly inclose each organ of the lateral line in the adult of Cottus, and to the bony half-rings which, according to Leydig (No. 9, p. 251) and Solger (No. 14, p. 111), support the walls and protect the organs in the cranial canals of Chimæra monstrosa. These semi-cylindrical pieces in Amia increase in length and soon become open gutters or channels. The plate then appears along the sides or toward the bottom of the channel, always continuous with it and growing from it on either side. The canal and the gutter in which it lies are always at this stage on the upper surface of the bone, thus corresponding to the conditions described by Bodenstein (No. 3, pp. 132 and 143) in the

os mastoideum of the adult Cottus. The gutters then become tubes, lying at first on the upper surface of the bony plates, and corresponding to the conditions found in the adult of some of the bony fishes.

The relations of the primary tubes to the various dermal bones in Amia are easily determined in a series of sections. They differ slightly from the relations of the trunks of the corresponding systems to the bones in the adult.

Trunk No. 2 infra-orbital enters its canal through the ethmoid; No. 3 between the ethmoid and the antorbital; Nos. 4 and 5 through the antorbital, and No. 6 at its upper posterior edge; No. 7 between the antorbital and lachrymal; No. 8 through the lachrymal; No. 9 between the lachrymal and first suborbital; No. 10 between the first and second suborbitals; No. 11 between the second suborbital and lower postorbital; No. 12 through the lower postorbital; No. 13 between the postorbitals; No. 14 between the upper postorbital and the postfrontal.

The double trunk 15–7 lies between the frontal and postfrontal and between the two anastomosing canals, which, at this point, change sharply their direction. The infra-orbital lies entirely in the postfrontal, and the supra-orbital entirely in the frontal; both of them along the open edges of the bones. The trunk of the system at this age is a large shallow pit into which the two canals open. In the further development of the system it deepens, becomes narrower, and lies over the point of anastomosis of the two canals instead of between them as at first. In the first division of the system the trunk divides after the manner shown in Cut 3, p. 18, *f* and *g*. One of the primary branches resulting from this division retains its position at the point of anastomosis of the two canals. The other travels backward along the infra-orbital canal till it reaches the anterior edge of the squamosal, where it is found in the adult (Fig. 40). The trunk of the system disappears.

Trunk 16 infra-orbital enters its canal through the squamosal. Immediately behind it is the double opening, 17–17, which lies at the lateral edge of the squamosal, between it and the upper end of the pre-operculum, and resembles closely the double pore 15–7. The upper end of the opercular line opens directly into the pit on its lower wall, and on the upper wall a small opening,

much smaller than the openings of the other pores, leads into the infra-orbital canal, which at this point is deflected toward the lateral edge of the squamosal. In the first division of this double system the trunk disappears, and the two primary branches travel downward along the opercular canal, at the same time separating somewhat along the line of that canal. The two secondary pores formed by this division also separate antero-posteriorly. From one of them arises the half-system lying in the adult in front of the canal (Fig. 40), and from the other that lying behind it.

Trunks 18 and 19 enter the main canal on either side of the extrascapula, between it and the squamosal and suprascapula respectively; No. 20 enters it between the suprascapula and supraclavicula; No. 21 through the supraclavicula, and No. 22–1 between the supraclavicula and the first scale of the lateral line.

In the supra-orbital line trunks 1, 2, and 3 all enter the canal through the nasal; No. 1 on its lateral edge; No. 2 on the anterior edge; and No. 3 through the top of the bone. Trunk 4 enters the canal between the nasal and frontal; Nos. 5 and 6 through the frontal; No. 7, as already described, between the frontal and postfrontal; and No. 8 between the frontal and parietal.

In the operculo-mandibular line, trunks 1 to 7 enter the canal through the dentary; No. 8 between the dentary and nasal; Nos. 9 and 10 through the angular; No. 11, a compound or double trunk, between the angular and pre-operculum; Nos. 12 to 16 through the pre-operculum; and No. 17 between the upper end of this bone and the lateral edge of the squamosal.

In the supratemporal cross-commissure the two lateral trunks on each side enter the canal through the extrascapulæ, and the large double median one between the two bones. By the first division of this median pore the two primary branches are formed, which, in the adult, become the trunks of the half-systems lying one on each side of the middle line of the head.

The conditions existing at this age and a little earlier show that a primary tube originally leaves each of the main lateral canals along its entire length between each two consecutive dermal bones, and that at every point of union of two canals, whether of the same or of opposite sides of the head, a double pore and trunk is formed, which give rise at this point to a double dendritic system.

If the bones containing the two anastomosing canals have anchylosed, or the two canals lie in the same bone, then both the pore and the trunk belonging to it entirely disappear.

The ethmoid in Amia is formed by the union of the two bones usually found in other fishes. At the line of union of these two bones, where the main infra-orbital canals of opposite sides unite, a single median pore and trunk have been formed and disappeared, as younger stages show. In like manner a pore and trunk have disappeared on either side at the point where the supratemporal commissure joins the main infra-orbital, these two canals here lying in the same bone, the extrascapula. *These two are the only trunks and pores that have disappeared in the entire system in Amia. In the adult, with two exceptions only, all of the primary tubes, which at younger ages issue from the main canals between consecutive bones, become partly or entirely inclosed in one or the other of these bones.* The two exceptions are trunk 4, supra-orbital, and the double trunk 17–17, which, even in the adult, lie wholly in the dermis.

2. Number and Position of the Canal Organs.

Between every two consecutive trunks, along the entire length of each canal, counting the double trunks twice, once along each of the anastomosing lines, and also counting the trunks that have disappeared, there is a single sensory spot or patch containing either a single well-developed organ of the kind called by Merkel (No. 12, p. 5) nerve-hillocks, and by Wright (No. 20, p. 480, note) neuromasts, or such an organ with one or more smaller ones developing at either end of it (Fig. 48, Pl. XLI.).

These sensory patches always lie inside the dermal bones, and there are along the infra-orbital line two in the ethmoid, four in the antorbital, two in the lachrymal, one in each suborbital, two in the lower postorbital, one in the upper postorbital, one in the postfrontal, three in the squamosal, one in the extrascapula, one in the suprascapula, and two in the supraclavicula. Along the supra-orbital line there are three in the nasal, and four in the frontal; along the operculo-mandibular, seven in the dentary, three in the angular, and six in the preoperculum; and in each half of the supratemporal cross-commissure three, all in the extrascapula, making forty in all on each side of the head.

The position of these organs in the canals, and their method of innervation, is shown in the diagrammatic drawing, Fig. 49, Plate XLII.

In this diagram two sense-organs, or groups of organs, are shown between the first trunks of the supra-orbital line on either side of the head, and one in this same line between trunks 18 and 19, directly opposite the point where the supratemporal cross-commissure joins it, with no trunk system between it and the first group of organs in this commissure. These two trunks and pores have disappeared, the position of the organs and the development of the system alone showing that they at one time existed. There is but one group of organs in the infra-orbital canal on each side of the double trunk 17–17, and only one between it and trunk 16 operculo-mandibular, showing that the double trunk, although displaced in the adult, belongs primarily at the point of union of the two canals. There is one group of organs on each side of the double trunk 15–7, between it and the next trunk, in the infra-orbital and supra-orbital canals, showing that the displaced primary branch, which in the adult issues between the squamosal and postfrontal, is in reality a part of the double trunk, and not a separate system. There is also but one group on each side of the compound trunk 11 of the operculo-mandibular line, between it and the next trunks of that line, and but one on each side of the median system of the supratemporal cross-commissure.

The fifth group of the infra-orbital line is apparently out of place, lying in what seems to be the trunk of system 6, above the point where the anterior commissure joins the suborbital part of the main canal. This is due to the fact that the end of the suborbital canal, beyond the point where the commissure joins it, has taken the direction of the commissure instead of retaining that of its own canal; so that what appears as the trunk of system 6 is in reality this trunk and the extreme anterior end of the main canal, and it is in this anterior end, and not in trunk 6, that group 5 lies. Moreover, system 6 being properly a terminal system in which the trunk continues the line of the main canal, there is nothing to indicate where it begins and the canal ends. Organs 1 and 7 supra-orbital and 1 operculo-mandibular occupy strictly analogous positions, apparently lying in the trunks of the neighboring terminal systems.

3. Sense-organs of the Spiracular Canal.

Wright (No. 20, pp. 481 and 489) has described a patch of neuro-epithelium at the upper end of the spiracular canal in both Amia and Lepidosteus. It is supposed by him to have developed in this canal, and hence to be of hypodermal origin. In the young of Amia this sensory patch is a group of organs exactly like the regular organs of the lateral canals, consisting, as they do, of a large central organ and two or more smaller terminal ones. The group lies in the median wall of the membranous spiracular canal near its blind upper end.

The spiracular canal in Amia (No. 20, p. 492) opens widely on the upper surface of the cartilaginous cranium, at the extreme anterior end of what is rather a diverticulum of the temporal groove of Sagemehl (No. 13, p. 188) than a part of the groove itself. The main groove lodges the anterior end of the trunk muscles, while the diverticulum, which lies wholly lateral to it, connected with it along its edge, lodges no muscles whatever. It contains only loose, fatty tissues, vessels, and nerves. The squamosal portion of the infra-orbital canal lies directly above this diverticulum, and that branch of the R. *oticus facialis* that supplies organs 15 and 16 of that line lies in it, running backward from the point where the nerve issues through the roof of the cranium median to and about on a level with the opening of the spiracular canal. A branch of this same nerve, given off just as it leaves its foramen, turns outward and downward into the upper end of the spiracular canal, and is distributed to the group of organs there in the same way that the nerves of the lateral canals are distributed to the organs they supply.

When it is remembered in connection with the innervation and position of this group of organs, that all the sense-organs which at this stage lie inside the canals of the lateral system, are in earlier stages found on the external surface of the head, it seems reasonable to suppose that this particular group in Amia, apparently so anomalous in position, was regularly developed in the epidermal covering of the head along with the other organs of the infra-orbital line, but, lying near the edge of the spiracular cleft, it wandered into this cleft as it was closed, and so acquired its present position. If this be so, the lining mem-

brane at the upper end of the spiracular canal must be ectodermal rather than entodermal in origin. No positive evidence of this method of development has yet been found, for in none of the postembryonic forms to which the present work has so far been confined has the spiracle been open. In some of the youngest specimens, however, certain appearances seemed to indicate that it had only recently been closed. In specimens from one to five days old there is always a strong depression immediately above the upper end of the opercular line (Figs. 1 and 3, Pl. XXX., *spr*). The developing infra-orbital line crosses this depression, and organs 15 and 16 lie in it. In freshly prepared one-day-old specimens there is in the bottom of the depression, immediately below these organs, a dark spot indicating the position of the blind upper end of the spiracular canal. This spot in some specimens is strongly marked, and if the tissues are fresh and somewhat transparent, has the appearance of being an opening with a part of the sensory tissue of the infra-orbital line extending into it or across its edge.

4. Lines of Pit Organs.

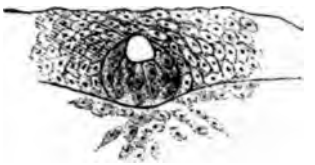
There are in Amia, in addition to the sense-organs found in the lateral and spiracular canals, several surface lines of somewhat similar organs, which, although belonging to the same general class of nerve-hillocks (Merkel), differ greatly from the canal organs in shape, arrangement, and method of multiplication. These organs are somewhat conical in shape, and, like the canal organs, represent the entire thickness of the epidermis at the points where they occur. In young fishes, and on the body in the adult, they project slightly beyond, or come nearly to the level of, the outer surface; but on the head of the adult they lie at the bottom of little pits, and therefore they may be called pit organs. They are found close together, in regular lines on slight dermal papillæ, and are connected by a special cord of cells which extends beyond the end of the line, and is lost among the general epidermal cells. They appear to develop independently along this cord.

Cut 5 represents a section through one of these surface lines in an adult; and Cut 4, one in a fish 45 millimetres long. Cuts 4 to 9 are semi-diagrammatic, but the outlines are taken from

actual sections. In Cut 4 is seen the cord along which the organs lie, and an organ developing in it. The organ at this

Cut 4.

Cut 5.



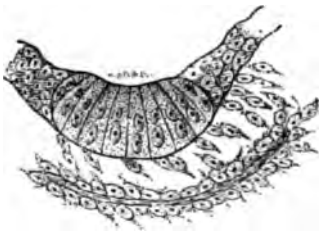
Cut 6.

Cut 4. — Longitudinal section through a line of pit organs in a fish 45 millimetres long, showing four organs, one of which is just forming, all connected by a cord of cells in the deeper layers of the epidermis.

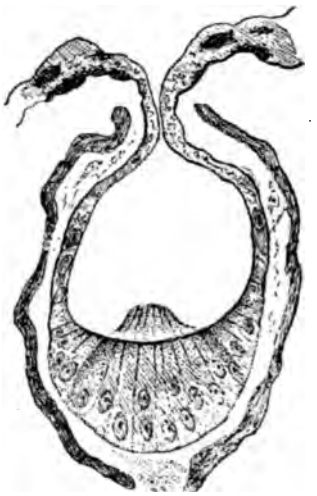
Cut 5. — Longitudinal section through a line of pit organs in the adult, showing three organs and the connecting cord.

Cut 6. — Section through a developing organ of the suborbital line in a fish 11½ millimetres long, showing large vacuolar space at top of organ.

Cut 7.



Cut 8.



Cut 9.

Cut 7. — The same in a fish millimetres long, where the organ has reached the other surface.

Cut 8. — The same in a fish millimetres long, where the organ is beginning to sink below the surface and the osseous canal is forming.

Cut 9. — The same in a fish millimetres long, where the canal is just closing over the organ, showing the nearly formed osseous canal and the nerve leading through it to the organ.

stage of its development has the appearance of a flat dome with a large, vesicle-like space, set like a keystone at the top of the structure. Toward this space the cells of the organ are directed, and as they increase in length, and the organ in height, the latter pushes its way, wedge-like, through epidermal cells, crowding them to either side, until it reaches the outer surface, where its upper central portion becomes exposed. It has now the shape of a cone with rounded summit (Cut 4); and its exposed upper end, which contains the compressed outer ends of all the sensory cells, reaches to the general level of the outer surface, or even projects beyond it. On the body, and particularly toward the tail, the organs retain nearly this condition even in the adult; but on the head they are later so much withdrawn from the surface that only a series of minute holes indicates their position (Cut 5).

Cut 6 is a section through the suborbital line in a fish 11½ millimetres long. It shows one of the canal organs in a stage corresponding to that of the young pit organ in Cut 4, and also to that of the organs of the lateral line in Salmon embryos before the organs have reached the outer surface, as shown by Hoffman (No. 8, Pl. V., Fig. 29). There is at the top of this canal organ the same vacuolar space that is found in the developing pit organ, and there are apparently no support cells. These appear later, after the organ has reached the outer surface, as shown in Cut 7.

In these early stages the different organs of a canal line are connected by a special cord of cells similar to that connecting the organs of a pit line. In Cut 8 the organ has begun to sink below the surface, and in Cut 9 the canal is just closing over it. As development progresses, the connecting cord of cells disappears, except immediately adjoining the organ, where it was present in the oldest specimen in which it was examined, one about 80 millimetres long. Along this remnant of the cord, and immediately adjoining the primary organ, the other organs of the group appear, at first as small bud-like organs, inclined away from the larger central one (Fig. 48, Pl. XLI). These new organs grow rapidly, and others soon appear in succession along the cord beyond them, all at first in contact at their bases, but separated above by projecting ridges of indifferent cells, exactly as figured and described by Blaue (No. 2), in the olfactory

epithelium of Exocœtus and other forms. The groups which thus arise are doubtless the beginnings of what Merkel has called nerve-ridges (No. 12, p. 20), for under this name he includes all organs found in the adult inside the canals of the lateral system (No. 12, p. 23). He also finds nerve-ridges on the surface in some fishes that have no canals, as Petromyzon, Squatina, etc., and describes them as simply an elongated form of the regular conical nerve-hillock, containing exactly the same histological elements, but with a larger proportion of support-cells. He further says, that in the teleosts the conical hillocks are always found on the surface or in slight depressions; that they may either be arranged in lines and groups, or scattered irregularly over the whole body; that they are most numerous in those forms that have but few openings to the lateral canals, or have no canals at all; and that where the canals branch freely, and there are many pores, the conical hillocks may entirely disappear, as on the head of Mullus. In the Selachians they are, according to him, found only on two species, Mustelus and Squatina, being entirely replaced in other forms by another kind of sense-organ, the nerve-ampulla (No. 12, p. 39); and in the Ganoids, he says, they are not found at all, being entirely replaced by still another kind of organ, the nerve-sack (No. 12, p. 36). This certainly is not true of all the Ganoids, for in Amia I have not been able to find any of the nerve-sacks which he considers peculiar to the Ganoids, and I have always found seven different lines of pit organs (his conical hillocks) on each side of the head, and two series of lines of organs on each side of the body.

Of the seven lines found on the head, three lie on top of it, two on the cheek, one on the side of the mandible, and one on the gular plate (Figs. 21, 22, and 23, Pls. XXXVI. and XXXVII.). Of the two on the body, one lies parallel to the lateral line, and the other on the top of the body close to the dorsal fin. Each of the lines on the head is a continuous series of organs, while those on the body in the adult are each made up of a series of such lines, one approximately to each segment of the body. No ventral body line could be found.

a. Head Lines. — The first or anterior one (Fig. 21, *al*) of the three dorsal lines of the head runs backward and medianward from group 8 supra-orbital; and the third or posterior one

(Fig. 21, *pl*) forward and medianward from group 2 supra-temporal. The second or middle one (Fig. 21, *ml*) lies between the other two, and extends almost direct medianward from near the double group 17–17. The first line lies superficial to the parietal. It begins close to, or among, the pores of group 8 supra-orbital, sometimes starting in or running across the edge of a pore so that one of its organs lies partly inside it. The second one lies superficial to the squamosal and parietal, just in front of the anterior edge of the extrascapula. It often ends close to the posterior end of the first line, the two almost meeting to form an angle. The third one lies superficial to the parietal and extrascapula, and usually extends much nearer the middle line of the head than the other two. In many specimens these six lines, three on each side, seem to radiate from a clear space directly on the crown of the head. This appearance is most marked in young specimens (Figs. 14, 15, and 16, Pl. XXXV.), in which *the anterior line begins close to pore* 8 *supra-orbital, and is a direct continuation of the line of that canal. The first organ of the pit line often lies partly inside the tube of pore* 8, *and in one set of sections was entirely inside it, somewhat modified in shape and about midway between the next following pit organ and the regular terminal organ No. 7 of the canal.* This organ No. 7 is inclosed in its canal much later than the other organs of the line, and is in specimens up to 45 millimetres in length much smaller, being still single while they are represented by groups of three or five.

The horizontal line on the cheek (Fig. 22, *hl*) begins among the pores of groups 14 or 15 of the opercular line, and ends among those of group 12 infra-orbital. It lies partly superficial to the lower postorbital, somewhat behind the centre of the bone, *and frequently runs directly into a pore of group* 12, *just as the anterior dorsal line does into the pores of group* 8 *supra-orbital. These two lines are the only ones in which this occurs, the other lines beginning at some little distance from the pores of the groups near which they arise.* The vertical line (Fig. 22, *vl*) begins behind or among the pores of group 12 infra-orbital, near the anterior end of the horizontal line, and, lying partly superficial to the lower postorbital, runs downward toward the pores of group 11 operculo-mandibular, or a little behind them. The mandibular line (Fig. 22, *mdl*) lies superficial to the angular,

and runs, in the shape of a letter S, from the anterior part of group 11 toward group 9 operculo-mandibular. The gular line (Fig. 23, *gl*) runs transversely across the gular plate between groups 7 and 8 on either side.

In the adult the bones immediately beneath these pit lines are slightly furrowed, and the lines are often broken.

Body Lines. — In the adult there is, on nearly every scale of the first two-thirds of the lateral line, a line of pit organs running across the scale immediately in front of the group of pores (Fig. 39, Pl. XXXIX., *all*). In young specimens these lines are each represented by a single organ lying immediately above the corresponding organ of the lateral line. In the development of the pit line these single organs are apparently connected by a cord of cells, not only with each other, but also with the corresponding organs of the lateral line. The line grows backward in the same way that the main line does, and may be called the accessory lateral line, a name already used by Solger (No. 17, p. 380) and others. In the adult the first series of pit organs is found on the third, fourth, or fifth scale of the line; in one specimen which was examined for this purpose no organ could be found behind the forty-fifth scale, there being in all sixty-seven scales in the lateral line. Toward the head there are always more organs in each series or line, some of them having as many as eight.

The first series of organs of the dorsal body line is usually found on the second row of scales, above and behind group 21 infra-orbital (Figs. 15, 16, and 17). This row of scales is the second or third row of the body, counting backward along the middle line of the back, or the second row, counting along the lateral line. Considering the rows transverse to this, — that is, those that run upward and backward, — the dorsal body line begins on the sixth or seventh row of scales and on the second row in front of the first scale of the lateral line. Still considering these transverse rows, the second series of organs lies on the row following that on which the first series is found, and on the second scale dorsalward along that row. The third series lies on the next row, usually four scales dorsalward from the second series, and on the second scale from the middle line of the body. It lies in the same row as the first scale of the lateral line. From this point the pit line runs directly back-

ward, and ends about opposite the anus. The different series of organs, after the third, lie one behind the other on the second or third scale from the middle line of the body, or on the second scale from the base of the dorsal fin ; and there is normally a series on each row of scales, the rows corresponding to the scales of the lateral line. The series or lines in front of the dorsal fin are transverse to the body, while those along either side of it are longitudinal.

In 55-millimetre specimens the different lines or series of the dorsal line, as well as those of the accessory lateral line, are still represented by single organs (Figs. 12 and 13, Pl. XXXIV.).

In both Lepidosteus and Polypterus the canal of the lateral line extends to the tail fin ; and in both there seem to be, from the descriptions given by Solger (No. 14, pp. 368 and 369), series of organs corresponding to the pit lines of the body in Amia. In neither form are the organs themselves described, but their distribution, as indicated by well-marked furrows, is fully given. In Lepidosteus the furrows are transverse, as they are in Amia ; and there are only two series, one on the back extending as far as the dorsal fin, and the other accompanying the lateral canal, and extending as far as the tail fin. The furrows of this last line lie, as in Amia, just in front of the pores of the lateral canal, and they are found on about one-half the scales of the line.

In Polypterus the furrows are longitudinal. The dorsal series extends as far as the tail fin, and a number of irregularly scattered furrows lying below the lateral line and immediately behind the pectoral fin represent what Solger considers a ventral series, not found in Amia. A third series of furrows is found on the scales of the lateral lines, but it is impossible to tell from Solger's description whether they represent lines of pit organs or the lateral canal itself not fully inclosed. Each furrow cuts through the hind edge of the scale on which it lies, and they are found on nearly every scale of the line. Immediately above them there is a series of depressions, which differ somewhat in appearance from the furrows of the lateral line while they closely resemble the transverse furrows in Lepidosteus. They doubtless represent the accessory lateral line of Amia.

In Fierasfer also there are several lines of organs which seem, from the descriptions given by Emory (No. 5, p. 40), to corre-

spond to the pit organs in Amia. They lie at the bottoms of flask-shaped epidermal pits, each of which contains a single organ. The external opening of the pit is about the size of the exposed upper end of the organ, and the organ which is smaller than, but similar to, those found in the lateral canals does not come in contact with the sides of the pit. They are found in lines or irregular groups on the head, and on the body in four lines or series of lines, a dorsal line, two accessory lateral lines, one immediately above and one immediately below the lateral canal, and a ventral line. The pits of the ventral line and those of the dorsal accessory line are all connected by small longitudinal canals formed in the deeper layers of the epidermis, and those of the ventral accessory line that are formed on a single segment of the body are similarly connected. The organs of the dorsal body line are not so connected; but canals extend transversely on either side of them, and end blindly in the epidermis, often branching toward the end. These epidermal canals have not been described in other fishes. They agree exactly in position with the cords of cells connecting the pit organs in Amia; and if these cords should be replaced by canals, or canals should be formed in them by deliquescence or otherwise, as the lateral canals themselves are formed in Selachians, the arrangement described by Emory would arise. The artificial separation of the cord from the overlying epidermal cells would probably produce a somewhat similar appearance.

5. Surface Sense-organs.

Under the name Terminal Buds Merkel includes a large class of organs, which, in Amia, always come to a level with or project slightly beyond the outer surface of the membrane in which they lie. They are found in great numbers on the external surface of the head, including the operculum, gular plate, and branchiostegal rays. They also extend on the top of the body as far as the dorsal fin; but behind this, and along the sides and belly, none could be found by surface examinations of the adult or by sections in young specimens, and none were found on any of the fins. They are also found in the mouth and branchial cavities.

In the adult they are scattered irregularly over the surfaces

where they occur; but in young specimens they are found in lines or series, connected more or less distinctly in hardened specimens by a whitish cord similar to that connecting the pit and canal organs at this age. They are first seen in specimens of from one to two days old as faint whitish spots adjoining a canal line, as shown in Fig. 4, median to the line of the supra-orbital canal. This spot soon breaks up into, or is replaced by, a series of spots, as shown in the four-day-old specimen represented in Fig. 5. In this specimen similar rows are also seen on the other side of the supra-orbital and on each side of the infra-orbital line, while faint markings on the cheeks, median to the squamosal and post-temporal part of infra-orbital, indicate still other places where they will soon appear. After this age the organs develop rapidly, and in specimens five days old (Figs. 6 and 7, Pl. XXXI.) they are already numerous on the anterior half of the head. In specimens ten or twelve days old (Figs. 8 to 11, Pls. XXXII. and XXXIII.) they appear on the operculum; and when the fish is from three to four weeks old (Fig. 13, Pl. XXXIV.), they have spread over the entire head and part of the body. In these older specimens the serial arrangement of the organs has disappeared, except in those parts of the head where they are just beginning to appear. In such places (Fig. 9, Pl. XXXII.) they are still found in rows, and more or less distinctly connected by a cord.

6. Innervation.

It is now well known that all the sense-organs belonging to the canals of the lateral system are innervated by dorsal branches of the cranial nerves. For these organs Beard has recently proposed the name branchial sense-organs, because of their development in early embryos from thickenings of the epiblast over each branchial cleft, and for the nerves the name suprabranchial nerves (No. 1, pp. 171 and 174).

According to his general scheme of development in Elasmobranchs, based largely on the researches of Balfour, Marshall, and Van Wijhe, the dorsal root of a cranial nerve grows outward and downward from the neural crest, toward a local thickening of epiblast already formed over the cleft of its segment. At the level of the notochord, it fuses with the epiblastic thick-

ening, a part of it, however, passing on as the future postbranchial nerve to the lateral muscle-plate of the segment. At the point of fusion, cells are rapidly proliferated. The deeper part of the mass which thus arises is the rudiment of the ganglion of the dorsal root, and the superficial portion, the rudiment of a branchial sense-organ. The deeper portion soon separates from the rest of the mass, leaving a nerve strand connecting it with sensory portion, and, lying deeper in the mesoblast on the root of the nerve, apparently at first distal to the point of separation of the post-branchial branch, becomes the ganglion of the nerve.

The superficial sensory part of the thickening may remain very small, or it may increase to a very considerable length, pushing its way either backward or forward, as the case may be, between the general epiblast cells, and connected in every case with the ganglion of the segment by the supra-branchial nerve, which is split off from under side of the thickening simultaneously with its growth. Along this thickening, concomitantly with the splitting off of the nerve, different organs arise, according to Beard, by the simple and repeated division of the single organ formed over the cleft, each organ so formed being connected by a separate branch with the main supra-branchial nerve.

This method of origin differs somewhat from that of the lateral line of Salmo, where, according to Hoffman (No. 8, p. 88), the different sense-organs arise independently after the lateral nerve has been split off from the under part of the epiblastic thickening which represents the line. As the nerve separates, a strand is left at each intermuscular septum connecting the nerve with the cells of the deeper part of the epidermis where later the organ will arise.

Beard's work was mainly confined to Torpedo ocellata, but he confirmed the results obtained in this form by comparison with the embryos of Mustelus and Pristiurus, and of certain Teleostei and Amphibia. In all these forms he finds seven supra-branchial nerves and seven corresponding lines of branchial sense-organs; but the position of these organs in the embryos is not fully detailed, and the adult conditions are not noticed at all, so that it is impossible to tell what becomes of the seven thickenings, and where, in the adult, the organs developed from each are to be found.

The seven supra-branchial nerves, as given by Beard, are the following: —

1. Ophthalmicus profundus,
   belonging to the ciliary ganglion and hypophysis cleft.
2. Ophthalmicus superficialis less portio facialis,
   of the gasserion ganglion and mouth cleft.
3. Portio facialis of Ophthalmicus superficialis.
4. Ramus buccalis,
   of the facial ganglion and two clefts, the hyoid and an absent one.
5. Supratemporal branch of the glossopharyngeal,
   of the glossopharyngeal ganglion and the first branchial cleft.
6. Supratemporal branch,
   of the first vagus ganglion and second branchial cleft.
7. Lateral nerve,
   of the second, third, and fourth vagus ganglia, and the third and following visceral clefts.

Of these seven nerves, the ophthalmicus profundus and ophthalmicus superficialis less portio facialis innervate, according to him, sense-organs lying over the snout; the portio facialis and ramus buccalis, the organs of the supra- and infra-orbital lines respectively; the glossopharyngeal and first vagus branches, the supratemporal organs; and the rest of the vagus, or nervus lineæ lateralis, the organs of the lateral line of the body.

The arrangement of the organs of the lateral system in Amia calva and their method of innervation, as determined by the examination of larval stages by sections, does not agree with Beard's scheme, for the trigeminal and ophthalmicus profundus take no part with any of their branches in the innervation either of the canal or pit organs. Moreover, there is the large and important operculo-mandibular line of organs, which Beard seems to have overlooked, for he does not mention it, and none of the suprabranchial branches given in his scheme of the sensory nerves could take any part in its innervation, unless the conditions in Torpedo and the other forms used by him for comparison are markedly different from those found in Amia.

In Amia the trigeminal, although it takes no part in the innervation of the regular canal or pit organs, has a large and

important part in innervating the surface sense-organs, or terminal buds. Its ophthalmic and superior maxillary branches are largely devoted to this purpose. They supply no muscles, and numerous branches can be traced in sections from each of them directly to the surface organs which they supply. The inferior maxillary is partly sensory and partly motor, several important branches of it being distributed entirely to the surface sense-organs and other non-muscular tissues.

The ophthalmicus profundus is also entirely sensory. A small branch pierces the choroid coat of the eye, accompanied by a branch of the external carotoid artery, while the rest of the nerve fuses completely with the ophthalmic division of the trigeminal, so that its special distribution cannot be determined. In one set of sections only of all those examined did there seem to be a separation of these two nerves on the top of the snout, the ophthalmicus profundus being lost in the general tissues above the nasal sacks, and doubtless taking part there, along with the trigeminal, in the innervation of the surface organs.

The facial is the first one of the cranial nerves that takes any part in supplying the regular organs of the lateral canals, and it has a large and important part not only in their innervation, but also in that of the different lines of pit organs. Four of its branches, the ophthalmicus superfacialis, buccalis, oticus, and mandibularis externus, are entirely devoted to this purpose.

The R. ophthalmicus superfacialis facialis supplies all the organs of the supra-orbital canal, a separate branch being sent from the main nerve to each group of organs. This branch pierces the bony canal of the line immediately below the central organ of the group, and after entering the canal sends a branch to each organ. This is the method of innervation in all the canals. Posterior to all the branches sent to the different groups of supra-orbital organs, still another branch — the most posterior one of the R. ophthalmicus — is sent to the organs of the anterior dorsal pit line, a separate, smaller branch being sent from it to each organ of the line. This nerve alone, or together with the branch to organ 7 supra-orbital, which leaves the main nerve close to it, probably represents the branch which, according to Wright (No. 26, p. 483), supplies the organs of the transverse commissure in Mustelus. Wright is inclined to consider

this most posterior of the dorsal twigs of the seventh in Mustelus as homologous with the ramus oticus in Ganoids and Teleosts (No. 20, p. 490).

The ophthalmic branch of the facial is closely associated throughout most of its course with the ophthalmic branch of the trigeminal, but there is apparently no interchange of fibres between them; and in the youngest specimens examined, the two nerves were wholly separate, although lying close together.

The R. buccalis facialis supplies the first thirteen organs of the infra-orbital line, and the R. oticus facialis the next three, making sixteen organs in all of this line supplied by the facial, or all those in front of the line of the opercular canal. The remaining organs of the infra-orbital line are innervated by the glossopharyngeal and vagus.

The sixteen infra-orbital organs supplied by the facial are separated by their innervation into four distinct groups. The first four, all belonging to the anterior commissure, form the first of these groups. They are supplied regularly by separate, consecutive branches given off from the anterior portion of the R. buccalis, which ends in the first one of them. The next six organs, from 5 to 10 inclusive, form the second group of the line, and they are also supplied by separate branches of the R. buccalis; but the branches to organs 5 and 6 are given off close together, the one to No. 6 passing outward behind the fifth division of the M. levator arcus palatini (McMurrich, No. 10, p. 122), and the other to No. 5, internal to, and in front of, this muscle. The origin of these two nerves close together from the main R. buccalis is easily explained by supposing the first four organs of the canal in Amia to have belonged to a line of pit organs in some earlier form. As the separate organs of such a line are always much smaller than those found in the canals, and as the nerve that supplies a whole line of them, where still found in Amia, is no larger, or not so large, as the branch sent to a single canal organ, the main part of the ramus buccalis would, in such an earlier form, have ended in the terminal organ of the canal; that is, in organ 5 of the line in Amia; and what is the anterior part of the nerve in Amia would, in that form, have been simply a smaller branch sent to the organs of the pit line, and given off beyond and rather close to the branch to organ 6, just as a similar branch, destined to supply

the organs of the dorsal pit line, is still given off in Amia from the end of the nerve supplying the organs of the supratemporal commissure. As this anterior branch became larger and more important, concomitantly with the change of the pit line to a canal, it would become the anterior part of the main nerve, and the branches to organs 5 and 6 would arise close together from it, as they do in Amia.

Organs 11, 12, and 13 form the third group of the line. They are innervated in different specimens by one or by two branches of the R. buccalis, the branches, where there are two of them, arising close together and close to the origin of the main nerve from its ganglion, and one of them supplies organs 11 and 12; where there is but one, the branch to organ 13 arises close to the origin of the nerve from the main R. buccalis; thus representing a stage in which the division of the nerve has not proceeded far enough to give rise to a separate branch. The branches to the different organs enter the bony canal of the suborbital line by separate passages, immediately below the proper organ.

The next three organs, Nos. 14, 15, and 16, form the fourth group of the line, and vary somewhat in their method of innervation. Organs 15 and 16 are always supplied by branches of the R. oticus facialis. This nerve arises directly from the facial ganglion. It runs upward and outward without entering the orbit, and, piercing the cranial cartilage, issues on the top of the chondrocranium at the extreme anterior end of the diverticulum of the temporal groove. It here separates into three branches, two of which supply organs 15 and 16, and one the organ at the upper end of the spiracular canal.

Organ 14 is sometimes supplied by a branch given off by the ramus oticus after it makes its exit on top of the cranium; but oftener, in the specimens examined, it was innervated by a branch which left the nerve close to its origin, or even from the facial ganglion itself, near the root of the oticus, but a little in front of it. This branch, after making its exit into the orbit through the regular foramen for the ophthalmic nerves, turns upward and reaches its proper organ without piercing the cranium at all, or passes through a special perforation in the overhanging cartilaginous roof of the orbit.

In young specimens the buccal and ophthalmic branches of

the facial arise from a Y-shaped mass of ganglion cells, formed on the dorsal root of the facial nerve, and lying on top of the rest of the trigemino-facial ganglionic complex, closely applied to it, but quite separate from it. The ophthalmic branch of the facial arises from the inner and upper arm of the Y, and the buccal from the lower and outer one. The otic and the branches to organs 11 to 14 infra-orbital, when they are not given off by the buccal, arise from the external side of the Y, and hence seem properly a part of the buccal. If this be so, and Beard's theory is to be accepted, then the original epiblastic thickening from which the infra-orbital line to organ 16 is developed, must have grown both forward and backward, the buccal being split off concomitantly with the growth of the anterior part, and the otic with that of the posterior, a few uncertain branches lying between them.

Organ 17 is supplied by the dorsal branch of the glosso-pharyngeal. This branch arises by a separate root, which passes out of the cranial cavity immediately behind the root of the main nerve, and often at this age by a separate foramen, or through a special part of the main foramen. On this root a separate ganglion is formed close to, and more or less intimately connected with, the main ganglion, and from it the dorsal nerve mentioned by Wright arises (No. 17, p. 489). This nerve runs upward through a special perforation of the chondrocranium, and, issuing on the bottom of the temporal groove, sends one branch to organ 17, the only canal organ supplied by it, and another to the middle dorsal pit line. This last branch runs medianward to about one-third the length of the pit line. It then turns upward and outward through the dermal bone, and dividing somewhat dichtomously, sends one branch medianward and another outward, both of them lying immediately underneath the line. From these branches smaller ones are given off directly to the separate organs. The innervation of this line indicates that it has grown in both directions from the original sensory spot found in younger specimens, and also that, although supplied by the same dorsal nerve that supplies canal organ 17, it is not a continuous growth from the epithelial thickening which was the rudiment of that organ. In this it differs from the other two dorsal head-lines, which grow from, and are directly continuous with, the rudiments of the canal organs from which they start.

The remaining organs of the infra-orbital canal, and those of the supratemporal cross-commissure, as well as the organs of the lateral line, are all supplied by branches arising from the ganglion formed on the root of the N. lineæ lateralis, or from that nerve itself. The arrangement here apparently departs somewhat from that given by Beard. The root of the N. lineæ lateralis receives its most anterior fibres at this age close to and a little above and behind the root of the N. acousticus. Piercing the membranes that separate the cranial cavity from the labyrinth, it runs directly backward, close to their outer surface and just above the posterior branch of the N. acousticus, in which there are numerous ganglion cells. It passes through the upper part of the main root of the glossopharyngeal, receiving there an important addition to its fibres, and, continuing backward immediately external to the origins of the anterior roots of the vagus, it issues through the main foramen of that nerve. In its passage through this foramen, it runs backward and outward, crossing the main root of the vagus at a considerable angle, and lying immediately above and closely applied to it. It probably receives here also an important addition to its fibres, but this could not be traced.

Immediately outside the foramen it forms a large, well-rounded ganglion, which lies directly above, and partly embedded in, the first vagus ganglion, but has no commissural connection with it, the line separating the ganglia in sections being perfectly sharp and distinct. From the proximal part of this ganglion, at its extreme anterior end, and almost from the root itself of the nerve, a large nerve is given off upward and outward. From it a branch is sent to organ 19 infra-orbital, and another, arising close to it, to organ 18, the rest of the nerve passing upward and medianward to supply the organs of the supratemporal commissure and those of the posterior dorsal pit line. The branch supplying the pit line is given off immediately beyond the branch to organ 2 of the commissure, thus agreeing in its relation to the other branches with that of the large branch sent by the R. buccalis to supply the organs of the anterior commissure, which branch is given off immediately beyond the branch to organ 6 infra-orbital, the second one of the suborbital line.

This dorsal nerve is described by Beard as the supra-branchial nerve of the first vagus ganglion. In Amia it is the first dorsal

or supratemporal branch of the lateral nerve. It is joined soon after leaving its ganglion by a branch arising inside the cranial cavity, either from the root of the lateral nerve or from the root of the vagus, which here contains numerous ganglion cells. This branch, although closely applied to the regular dorsal nerve, is wholly separate from it. It is distributed entirely to the general tissues of this part of the head, including doubtless the surface organs, although the direct connection with any of them was not determined.

The next or second regular dorsal branch of the lateral nerve is given off near the base of the nerve, and not from the ganglion. It supplies organ 20 infra-orbital and the dorsal pit line of the body, branches being sent in succession to each organ or series of organs of that line. Other dorsal branches of the lateral nerve are then sent in succession to organ 21 infra-orbital and the organs of the lateral line of the body.

The lateral nerve has an undulating course, as shown by longitudinal horizontal sections (Fig. 48, Pl. XLI.). Each full undulation of the nerve corresponds to a muscle segment, and from the outer crests of each the branches sent to the organs of the lateral line arise. Running outward along the intermuscular septa, they pass through the corium, and then backward along the under surface of the scale they supply. Reaching the anterior end of the section of canal contained in this scale, the nerve enters it through a special passage, and supplies the single organ or groups of organs found there in the same way that the organs of the head are supplied. Each of these nerves, before reaching the under surface of the dermis, sends a branch upward and outward through the corium, a little dorsal to the point where the main nerve pierces it. Arriving under the same scale, this branch runs backward, dorsal to and parallel to the main nerve, and, piercing the scale about opposite the regular canal organ, supplies the corresponding series of pit organs.

The organs of the operculo-mandibular line are all innervated by branches of the R. mandibularis facialis externus. The first one of these branches is given off before the externus has separated from the main truncus hyoideo-mandibularis facialis. Leaving the truncus immediately after its passage from the facial canal through the hyomandibular, or even while still in

that canal, it runs outward, backward, and upward, and enters the bony canal of the opercular line immediately under organ 15. It sends a branch to this organ, and then continuing upward inside the bony canal, immediately underneath the epidermal lining, ends in organ 16, the last one of the line. Organs 14 and 13 are supplied by separate branches, given off either from the mandibularis externus or from the main ramus mandibularis before it has separated into an external and internal portion. Organs 12 and 11 are supplied by a single branch, which, as in the case of the branch to organs 15 and 16, enters the bony canal under the first organ supplied, No. 12, and then passes on inside the canal to the second one, No. 11. Where these branches are given off from the main ramus mandibularis or the main truncus, it is from that part of the nerve that contains the fibres which afterward separate as the externus. Beyond the branch to organs 12 and 11, separate branches are sent in succession to each organ up to No. 4. The nerve then enters the bony canal, and running forward inside it, supplies in succession organs 3, 2, and 1.

Between the single branch that supplies organs 15 and 16, and the next regular one to organ 14, a branch is sent outward through the adductor mandibulæ muscle and then forward along its outer surface, immediately underneath the horizontal cheek line, branches being sent in succession to each organ of the line. A similar nerve is given off between the branch to organ 13 and the one to organs 12 and 11. This nerve also passes outward through the adductor muscle, and then forward along its outer surface, but it soon separates into two parts, one of which goes to supply the vertical cheek line, and the other the pit line on the mandible. In both cases the nerve arrives near the middle of the line it supplies, and there separates into two parts which run toward either end of the line, sending separate branches to each organ. In one specimen the nerve supplying these two pit lines was not given off as a separate nerve from the externus, but as a branch from the nerve supplying organs 12 and 11.

The innervation of the line of the gular plate could not be fully determined. Branches can be traced from the different organs of the line to a single nerve which runs backward internal to the plate. At the hind edge of the bone the nerve

turns dorsalward, and, lying close beneath the epidermal lining of the dorsal side of the gular plate, runs forward dorsal to the hind edge of the geniohyoid muscle. Here it turns upward and backward, and then immediately upward and forward toward the front edge of the hyohyoideus muscle, round which it turns upward and backward, and, passing external to the front end of the sternohyoid muscle, enters the first branchial arch, and joins a part of the main nerve of that arch. This main nerve, so far as could be determined, is formed by the union of the post-branchial branch of the glossopharyngeal and the prebranchial branch of the first vagus ganglion. At the point where it is joined by the nerve of the gular line it has just separated into two parts, one of which runs downward and inward, and the other upward and inward, to be distributed to the tissues on the upper surface of the hyoid apparatus. It is this last branch that is joined by the nerve of the gular line.

7. Review of Nerves and Organs.

Reviewing briefly the arrangement of the nerves and organs, there are in front of the double pore 17–17, where the opercular and infra-orbital lines unite, sixteen separate canal organs or groups of organs along each line. The last two organs on each line, Nos. 15 and 16, are supplied by branches of a single nerve, which is directed posteriorly along the canal. Organs 11 and 12 of each line are also supplied by branches, directed anteriorly, of a single nerve; while the intermediate organs, Nos. 13 and 14, are in most cases supplied by independent branches. On the infra-orbital line a branch of the otic, anterior to organ 15, supplies the organ or group of organs of the spiracular cleft; while on the opercular line a branch of the mandibularis given off next in front of the single nerve to organs 15 and 16, and hence in a corresponding position, supplies the organs of one of the surface lines of the cheek. The other cheek line and the surface line on the mandible are supplied by a single nerve, which, in one of the two sets of sections in which it was traced, arose as a branch of a nerve supplying a regular canal organ. The possible significance of this will appear in considering the arrangement of the dorsal nerves behind the facial. The horizontal cheek line ends close

to organ 11 infra-orbital; and the vertical cheek line, close to organ 11 operculo-mandibular. In front of this the canal organs on both lines are innervated by separate branches from the main nerve of the line.

Behind the point where the infra-orbital and opercular lines unite, organ 17 is supplied by the dorsal branch of the glossopharyngeal, which also supplies a line of surface organs lying dorsal to it. The next dorsal nerve, the first branch of the lateral line nerve, supplies organs 19 and 18, the organs of the supratemporal commissure, and a line of pit organs dorsal in their innervation to all of these. The second branch of the lateral nerve supplies organ 20 and the dorsal body line of pit organs. The next branch, so far as could be determined, supplies organ 21 alone; but each of the following branches for nearly the full length of the line normally supplies an organ of the lateral line and a corresponding line of pit organs.

The supratemporal cross-commissure, in the Characinidæ (No. 13, p. 36), lies in the parietals, and according to Sagemehl is an independent formation not to be compared with the commissure in Amia. So far as can be determined from his description, it occupies about the position of the middle dorsal pit line on the head of Amia. If it has the same innervation as this pit line, that is by the glossopharyngeal, a not improbable supposition, its exceptional position can easily be explained; for a canal line in one form is often represented by a pit line in another, as for instance, the anterior commissure in Amia and the corresponding pit line in Esox or Salvelinus; and probably also the anterior dorsal pit line in Amia and the cross-commissure in Mustelus, which has a corresponding position and apparently the same innervation.

In Fierasfer (No. 5, p. 38) the arrangement of the canals in this part of the head is markedly different from that in Amia. The cross-commissure leaves the main canal near the hind end of the squamosal directly opposite the upper end of the opercular canal, apparently as a direct continuation of that canal. It is innervated by the "ramus ascendente" of the lateral nerve, a branch which corresponds to or comprehends, according to Emory, both the supratemporal (probably of vagus) and opercular branches in other fishes. The "ramus ascendente" innervates not only the organs of the commissure, but also those in the

temporal part of the main canal and in the upper end of the operculo-mandibular. The glossopharyngeal, which in Amia supplies a canal organ and line of pit organs lying almost directly above the end of the opercular canal, is in Fierasfer distributed entirely to the first branchial arch, and takes no part in the innervation of the lateral system.

Variations. — The arrangement of the canals and organs of the lateral system given in the preceding descriptions is the one most commonly found; but there are frequent variations, due either to the complete disappearance, or to the addition, of one or more peripheral systems. A group of sense-organs and its nerve appear or disappear with the addition or disappearance of a system. No exception to this rule was found in Amia; but in one specimen of Amiurus, a primary tube was missing in the mandibular line without the disappearance of a corresponding nerve and organ, thus leaving two separate organs or groups of organs between two consecutive tubes. This was doubtless due to the abnormal closing of a tube after its regular formation.

In Amia the most frequent variation from the normal type was the disappearance of one sense-organ and corresponding primary tube in the mandibular canal, leaving nine organs, tubes, and pores along the lower edge of the mandible instead of ten. The missing system was always one of those normally found in the angular. Less frequently there was the addition of one system, or the disappearance of two, along this same canal, the number along the opercular part of the line always remaining constant.

Other variations were the addition or disappearance of a single system along that part of the suborbital canal that lies in the postorbital bones, and the addition or disappearance of one in the one-half of the supratemporal cross-commissure, the other half of the commissure often varying inversely, so that the total number of systems in the full commissure remained the same. The organ that is missing when there is one system short in the suborbital line is either No. 11 or No. 12, both of which normally lie in the lower postorbital, and are innervated by a single branch of the R. buccalis. No variations were found in the supra-orbital line.

Van Wijhe (No. 19, p. 285) has called attention to the regular

correspondence of each scale of the lateral line in Amia to a segment of the body, and has suggested the possibility of some sort of relation between the dermal bones of the head and the cranial segments. The arrangement of the sense-organs and nerves of the lateral system, the regular occurrence of primary tubes between consecutive dermal bones of the head, as well as between consecutive scales of the lateral line, and the singular correspondence between the infra-orbital and opercular canals is further evidence in this same direction.

III. LARVAL FORMS.

1. Formation of the Canals.

The inclosing of the lateral canals and the formation of the ninety-three normal primary pores and tubes is essentially a simple and regular process, but in most parts of the head marked abbreviations take place, which greatly obscure it. Where the process is regularly and fully carried out, the canals arise in separate sections, each of which contains a single sense-organ, and hence corresponds to the part between two primary tubes in the developed canal. This has already been described by Bodenstein in the lateral line of Cottus (No. 3, p. 142) and by both Schulze (No. 16, p. 69) and Solger (No. 18, p. 386) in Plateria.

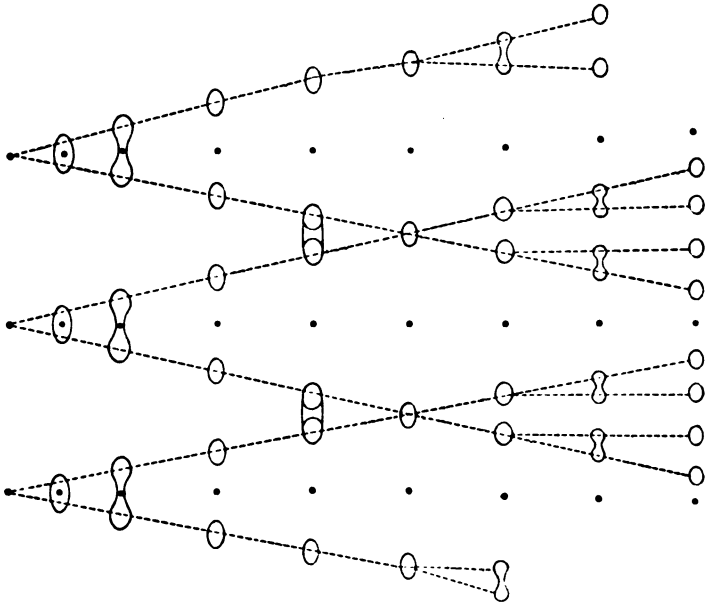
If young Amia, in which the canals have not yet begun to develop, are hardened in chromic or picro-sulphuric acid, the organs of the lateral system, still below the surface, appear as whitish spots, with indistinct outlines, strung along more or less continuous whitish lines. These lines mark general and extensive surface depressions. After a developing canal organ has reached the surface at the bottom of one of these depressions, it begins to sink, carrying with it the surrounding tissues, thus forming a small pit, at the bottom of which the organ lies. A series of changes now begin, which, on an exaggerated scale, are a repetition of those which lead to the division of a pore. Lips grow upward and inward from the edges of the pit, and, meeting above the organ, form a short section of canal, the openings of which are inclined to the general surface, and give to the canal a tunnel-like appearance. A narrow shallow channel, pigmented like the rest of the outer surface, has meantime

formed between the organs along the bottom of the general depression. It is deepest near the newly formed section of canal; and into it the canal opens, the sides of the openings passing gradually into the walls of the channel. The limits of the canal are clearly defined by a sharp change in direction of the bottom of the channel, the canal leading inward at something of an angle, the walls of the canals and pits always being much lighter in color than the outer surface.

The openings of these short sections of canal may be called half-pores because, with a few exceptions, all the primary pores in the developed system are formed by the fusion of two of them. After its formation the short canal increases in length by the continued coalescing of the edges of the channel immediately beyond it, and the two half-pores are pushed apart along the line of the canal toward other pores which are in a similar way approaching them from adjoining sections. This process in Amia is continued until the pores meet and unite, thus forming a continuous canal with a primary pore and tube between every two consecutive organs; but it may be arrested, in which case an interrupted canal will be formed, as in the post-temporal part of the infra-orbital in Esox lucius and along the canal of the lateral line in Ophidium (No. 5, p. 39). At each end of a continuous canal formed in this manner it is evident there must be a pore, which, if it cannot unite with a pore of some other line to form a double system, must always remain a half-pore or terminal opening. Such terminal openings are retained in Amia in pores 1 and 8 supra-orbital and 1 operculo-mandibular. The other terminal opening of the opercular line, pore 17, unites with pore 17 infra-orbital to form a double system. In the infra-orbital line pore 6 is a terminal one, and pore 22–1 a double one, formed at the other end of the line where it joins the lateral canal of the body. In the anterior commissure one terminal opening has disappeared on the top of the snout where the two lines meet, and the other has fused with the second pore of the main canal to form what has been called pore 5 infra-orbital.

Cut 10 is a diagrammatic representation of the formation and subsequent subdivision of a primary pore. These two processes are continuous and essentially similar; for even in the adult, two pores if forced together from want of space fuse, as fre-

quently happens along the lower edge of the lachrymal. Double pores of this kind, formed in the adult, usually undergo no further division; but the conditions shown at *omg''* in group 11 operculo-mandibular (Fig. 20, Pl. XXXVI.) can only be explained on the supposition that this pore has afterward subdivided and multiplied exactly as do the simple pores.



Cut 10. — Diagrammatic representation of the formation of pores and groups of pores. The small black spots indicate organs, and the curved outlines openings of pits or pores in different stages of formation and division.

All phases in the formation of half-pores, as well as of the primary ones, are shown in Figs. 23 to 34, which fully illustrate the development of that part of the infra-orbital canal lying immediately behind the eye. The formation of the first few pores of the lateral line and the last three pores of the infra-orbital are shown in Figs. 35 to 38.

In Fig. 23, which represents a specimen 19 millimetres long, and from twelve to fifteen days old, organ 16 infra-orbital is just inclosed, an unpigmented line still marking where the sides of the canal have come together above it. Organ 15 lies in a deep groove continuous with the canal at organ 16, and is about to be inclosed. The inclosing of these two organs is an abbrevia-

tion of the regular method. They lie relatively close together, and the pits in which they lie become a continuous groove, as shown in Fig. 12, before the canal closes over either of them. The canal is formed as usual, but a relatively long section of it is inclosed at once so that the two half-pores which go to make pore 16 are formed facing each other and already partly fused. The different steps in this process are shown in Figs. 23, 24, and 25, in the last of which pore 16 is fully developed. This abbreviated method occurs wherever the organs lie close together, or where the canals are relatively large, as in young larvæ.

In Figs. 23 and 24, organ 8 supra-orbital lies on the surface, and is hardly to be distinguished except by position from the following organs of the anterior dorsal pit line. In Fig. 25, which represents a 23½-millimetre specimen, it is just being inclosed, and in Fig. 27, a 29-millimetre one, is entirely so, pore 8 appearing as a small terminal opening immediately in front of the first organ of the pit line.

In Fig. 23, organs 14 and 15 infra-orbital can both be seen; in Fig. 24 they are just inclosed; and in the succeeding figures up to 28 the principal phases in the formation of pore 15 are shown. This pore lies at a sharp bend in the infra-orbital line close to pore 7 supra-orbital, which also lies at a bend in its line. The two lines are approaching each other at these bends, and the surface between them is strongly depressed, just as it is between successive organs on a regularly developing line. Along this depression pores 15 and 7, once formed, approach each other and coalesce, exactly as half-pores do along the line of a canal. In Figs. 29 and 30 they are shown partly united, and in Fig. 31, a 40-millimetre specimen, they have already united and begun their primary division, which is completed in Fig. 33, a 54-millimetre specimen. In Fig. 34, a specimen 135 millimetres long, the double pore has undergone its secondary division, and is represented by a group of four.

In Figs. 23 and 24, organ 16 operculo-mandibular and all the organs of the infra-orbital line behind organ 16, lie on the surface or in small pits along the strong channels which mark the course of the canal. In Fig. 25 the canal is closing over organs 17, 19, and 20. In Fig. 26 it has fully closed over organs 17 and 19, but organ 20 is still visible in a large double pit common to

it and to organ 21. In Fig. 27 the canal has closed over organ 20 and is about to close over organ 21, the process being so greatly abbreviated that pore 21 is formed at once in place. The two halves of pore 20 are always formed at some distance apart, as shown in Figs. 26, 27, and 28.

In Fig. 26 the two half-pores that go to form pore 17 infra-orbital are some distance apart. In Fig. 27 they are nearing each other, and in Fig. 30 they have united. The pore so formed is also beginning, in this figure, to travel down the opercular canal toward the terminal pore 17, which is formed by the closing of the canal over organ 16. In Fig. 33 the double pore 17–17 is nearly formed, and in Fig. 34 it has undergone its first division.

The formation of pores 18 and 19 infra-orbital is somewhat irregular. Organs 2 and 3 of the supratemporal commissure are usually the first ones inclosed, but in Fig. 27 the canal has formed over organs 1 and 3, and not over organ 2. The lateral terminal opening of the commissure, pore 4, lies directly opposite organ 18 infra-orbital, and a little in front of and behind this organ are the anterior and posterior halves of pores 18 and 19. In Figs. 28 and 35, which represent the same specimen, the canal is beginning to close over organ 18, the upper lip of the canal forming at the end of the commissure directly above its terminal opening. In Figs. 29 and 36, which also represent the same specimen, the canal has nearly closed over organ 18, and in Figs. 30 and 31 the process is completed, the terminal opening of the commissure being entirely shut off from the exterior,—transferred, in fact, from the exterior to the inner wall of the infra-orbital canal. In two of the specimens examined by section there was an extra pore and tube at this point, both small, the tube leading forward and medianward from the point where the commissure joined the main canal.

In Fig. 34 pores 18 infra-orbital and 3 supra-orbital have undergone their first division. In this figure the median terminal openings of the half-commissure of each side have united and undergone their first division. This division frequently takes place before the two terminal pores have fully united, and in such cases the median pore never gets beyond the oblong shape shown in Figs. 32 and 33. The same thing often occurs in pore 17 infra-orbital, which may undergo its first division before

it is fully formed and before it has united with pore 17 operculo-mandibular, as shown in Fig. 13. In this case only the anterior one of the secondary pores takes part in the fusion with the opercular line.

The canal of the lateral line, like the canals of the head, is first formed in short sections, which afterward become continuous. The rudiments of the different organs of the line are formed on the intermuscular septa, as described by Bodenstein and others in the bony fishes; but as the organ develops, it travels backward, and before being inclosed lies in the middle of the segment, as shown in Figs. 35 and 36, and as found by Malbranc in the Amphibia (No. 11). The organ then sinks into a little pit, and on its dorsal and ventral sides lips are formed which coalesce, forming a short canal about the length of a body segment, as seen in Figs. 36 and 37. The primary pores formed by the union of the terminal openings of these short sections lie at first opposite the intermuscular septa and between consecutive scales, which at this age have only the length of a body segment and no free edge (Fig. 37, *llp*^{1} and *llp*^{3}). As the scale grows its free hind edge pushes backward on either side of the primary tube and, uniting beyond it, leaves the pore on its outer surface (Fig. 38) and the tube at the point where the canal passes from one scale to the next (Fig. 48). The tube at first runs directly outward through the scale, but later it acquires a longitudinal position, extending backward almost as a prolongation of the short canal, and having on the outer surface of the scale one or more pores (Fig. 44).

Toward the front of the head and along the mandibular line the canals are inclosed much earlier than in the parts behind the eye. The process in this part of the head is always greatly abbreviated after the manner detailed in describing the formation of that part of the infra-orbital canal containing organs 15 and 16. The development also proceeds so rapidly here that the canals in this anterior part of the system are fully formed before those behind it have much more than begun to develop. This anterior part includes the first six organs of the supra-orbital line, the first ten of the infra-orbital, and the first nine of the operculo-mandibular. The canals inclosing these organs appear in specimens only five or six days old, and when the fish is from twelve to fifteen days old they are fully formed.

Figures 6 to 12 show the formation of these canals in three specimens, — one 11½ millimetres long (Figs. 6 and 7), one 14 millimetres long (Figs. 8 to 11), and one 18 millimetres (Fig. 12). As shown in these figures, the supra-orbital canal in front of organ 7 is inclosed in two sections containing three organs each, and the mandibular canal in a single section containing the first nine organs of the line. In the infra-orbital line organs 3 to 7 are inclosed together in a Y-shaped section of canal, and then organs 1 and 2, and 8, 9, 10. The median pore No. 1 formed in this process is shown in Fig. 11. It afterwards entirely disappears.

Organ 5 infra-orbital is normally the first one in the whole lateral system to be inclosed, and the formation of that part of the canal in which it lies is closely associated with the development of the nose. In Fig. 1 the nose is shown as a simple pit lying beyond the line of the infra-orbital canal. It is at first round and deep, but it soon becomes oblong, as shown in Fig. 4, and is then inclosed exactly as the canals of the lateral system are, a short section of canal being formed open at both ends and continuous behind with the Y-shaped open depression of the infra-orbital line. This stage is shown in Fig. 6, an unpigmented surface line still showing where the canal has closed over the nasal pit. The whitish cord of the infra-orbital line extends beyond organ 5 toward and partly into the posterior one of the two openings. In the 14-millimetre specimen, Fig. 8, organ 5 has been inclosed, and the half-opening, destined to become pore 6, stands facing the posterior naris, connected with it by a deep depression. At this stage these two openings appear like two half-pores about to fuse, but this resemblance soon disappears. In the 18-millimetre specimen, Fig. 12, the two pores still open into a large common depression, but it is becoming shallower; in Fig. 13, a 31-millimetre specimen, it has nearly disappeared; and in Fig. 14, entirely so, pore 6 now having a position in front of the naris instead of below it as at first. The formation of pore 5 infra-orbital from three half-pores is shown in Fig. 8.

In the opercular line the central part of the canal is formed at an early age. Organs 13 and 14 are the first to be inclosed (Fig. 12), then organs 12 and 15, and finally, at a much later period, organs 11 and 16. During this stage of its development

the opercular canal is an independent canal not connected with the mandibular portion, or with the main line, a condition which is permanent in Esox lucius.

The lateral canals of Amia present a more highly developed arrangement than those of the bony fishes. Lepidosteus, judging from a most cursory examination, resembles Amia; Polypterus, except in the possession of large dermal plates, has essentially the arrangement found in Amia immediately after the formation of the primary pores and tubes, and before the opercular line has joined the main canal. This larval arrangement in Amia also corresponds to that found in the adult of most bony fishes, but in many teleostean forms still more primitive conditions exist.

Sagemehl has advanced the theory that the teleostean condition is derived directly from that found in the adult of Amia by the gradual growth of a thicker cutis from the edges of the dermal bones toward their centres. As a result of this growth, the bones lose their superficial position, and finally lie beneath a thick dermis. The lateral canals, however, in order to maintain their communication with the exterior, do not sink in a corresponding degree, and they are accordingly found in the Teleosts much nearer the upper surface of the bone than in Amia. In many species they project in ridges above it, and in Gymnotus, many of the Murænidæ, some Cyprinoids and others, they lie entirely above the bones of the head inclosed in bony tubes and forming the "nervenskelet" of Stannius. In Polyodon Spathula, also, clearly a more primitive form in this respect than Amia, a somewhat similar arrangement exists; for, according to Van Wijhe, the canals lie in the flesh in open, bony channels. These different conditions both in the Teleosts and in the Ganoids would also be obtained if the development, as shown in Amia, was simply arrested instead of undergoing retrogression; that is, by supposing that the Teleosts had never attained the Amia condition instead of having passed through it as indicated by Sagemehl.

In Salvelinus the canal of the lateral line is never developed, and the peripheral systems of the cranial canals have, in most cases, only a single surface opening corresponding to the primary pores of Amia; but in one very large specimen, two of these systems had undergone a primary division similar to that

which takes place in Amia, and the two pores, always found single in other specimens, were each represented by a group of two.

2. Origin of the Canal Organs.

The discussion of the origin and growth of the sensory thickenings from which the different lines of the lateral system arise, and the origin of the sense-organs along these lines, lies wholly beyond the scope of the present paper, but the order and manner of their appearance, as determined from surface examinations, lies fairly within it. Most of the specimens used in this part of the work were killed in picro-sulphuric acid or chromic acid, with, or without, a trace of osmic, or in the vapor of osmic acid, and then transferred to chromic. Chromic acid was found to emphasize the continuity of the whitish lines which represent the sensory tissues, while picro-sulphuric produced a somewhat opposite effect, making evident a want of continuity, or at least a difference in the composition of the lines in those places where the innervation changes. Freshly killed specimens were found to give much the best results, for the use of alcohol obscured the markings which in certain places are indistinct even in the best preparations.

In fishes just hatched, the lines of the infra-orbital, supra-orbital, and lateral line canals are the only ones that can be distinguished. They are all represented by short, straight, raised lines of about the same length. That of the lateral canal starts immediately above the opercular opening, and those of the other two close together (if not from a common point), immediately behind the eye and directed, like the arms of a letter V, one above and the other below it. In somewhat older specimens the infra-orbital line extends under the eye to the level of the hind edge of the nasal pit, where it ends in an enlargement, from which later (Fig. 1, Pl. XXX.) the anterior commissure is given off downward and forward, the main line continuing upward toward the nasal pit. Behind the infra-orbital line, and immediately above the opercular opening, there are at this age two short, curved, comma-like lines directed upward and backward with their enlarged ends behind. The anterior one is the rudiment of organ 17 and the middle dorsal pit line, and the other the rudiment of the supratemporal and posterior dorsal pit lines. They both lie on the anterior end of a raised surface which is continuous with the dorsal part of the body muscles,

and is faintly indicated in Fig. 1. The dorsal outline of this raised portion curves downward, leaving a semi-transparent space in front of it, between it and the hind edge of the cerebellum. Its curved surface forms an angle behind with the curved surface of the yolk, the line of the angle extending backward and upward from the hind edge of the opercular opening to the anterior end of the line of depression between the dorsal and ventral muscle segments of the body. At the angle formed by these two lines of depression, at some distance behind the supratemporal line, the lateral line begins, as does also the accessory lateral line.

In specimens less than a day old, or even in those a little older, the lines or regions supplied by different nerves are distinctly separate in picro-sulphuric preparations, but in chromic acid ones much less so, particularly when first killed in the vapor of osmic. In such specimens the infra-orbital line is somewhat continuous throughout its length. In fishes two and one-half days old this appearance is still more marked, as shown in Fig. 1, which is drawn from a chromic acid preparation. The sense-organs of the different lines in this specimen are not yet sufficiently developed to show on the surface; but the raised whitish lines, which indicate the positions of the cords of cells along which they arise, are strongly marked. The line of the supra-orbital canal is continuous with that of the anterior dorsal pit line, and widely separated from the infra-orbital at the point where later the anastomosis with it will take place. Both ends of the line are enlarged where, according to the theory of Beard and others, it is pushing its way through the surrounding indifferent epithelial cells. The infra-orbital line is continuous throughout its length, and continuous with the lateral line which extends beyond the pectoral fin nearly to the level of the hind edge of the yolk. The accessory lateral line, which has just begun to develop, starts from the lateral line immediately behind the line of the supratemporal commissure, and is pushing backward through the surrounding cells exactly as the lateral line does. The ends of both these lines are enlarged, that of the lateral line sometimes forming a large and prominent swelling. The dorsal body line has not yet appeared. The posterior dorsal pit line of the head is continuous at an angle with the line

of the supratemporal commissure, which is represented by a single whitish spot connected by a cord with the infra-orbital line. These two lines are short and indistinct. They lie behind the upper end of the opercular opening and immediately behind the slight prominence of the auditory vesicle. The middle dorsal pit line is represented by a large spot lying immediately superficial to the auditory vesicle, and connected by a faint cord with the line of the infra-orbital.

Just in front of the auditory vesicle, the infra-orbital line runs across a depression, in the bottom of which, immediately below the line, is a dark spot marking the blind upper end of the spiracular canal. Above and in front of this point the line is enlarged; and from this enlargement organs 14, 15, and 16 arise. No opening into the spiracular canal could be found at this age or in one-day-old specimens. Behind and below the eye, the infra-orbital line is small; but in front of it, where organs 7 and 6 arise, it is enlarged again. In front of this enlargement it again narrows; and the line of the anterior commissure is given off, the main line continuing on toward the nasal pit, and ending there in an enlargement which is indistinctly continuous with the whitish border of the pit.

The operculo-mandibular line is a slender and faint but continuous line, lying along the anterior edge of a depression which marks the boundary between the operculum and branchiostegal rays on one side and the pre-operculum and mandible on the other. Its upper end lies in line with the spiracle, but is separated from it and from the infra-orbital by a strong prominence. A slight depression indicates the position of the horizontal cheek line, and another that of the vertical one.

The raised whitish lines which in these early specimens represent the growing sensory tissues disappear as the separate organs of the line develop, and there is left a slender white cord connecting them. This cord is doubtless the one found by Bodenstein in the adult of Cottus gobio (No. 3, p. 136), where it must be much more strongly developed than in Amia, for even in specimens only 40 millimetres long (or from twenty to thirty days old) it is traced with difficulty in sections. It is apparently the remnant of the cord along which the organs develop. In the four-day-old specimens, shown in Figs. 4 and 5, these cords are well defined, and most of the canal organs rec-

ognizable. The organs of the supra-orbital line are well developed, the first six being widely separated from the seventh and last, which cannot be distinguished in outward appearance from the pit organs lying immediately behind it. The cord connecting the canal organs is continuous with that connecting the organs of the pit line. On the infra-orbital line all of the organs up to No. 16 have appeared; and all, excepting Nos. 1, 6, 11, 12, and 13, which are always the last ones in this section of canal to be fully developed, have reached the outer surface. Organ 5 lies above the point where the anterior commissure and suborbital canal unite, and may from its position belong to either line. Up to No. 16 the cord of the line is continuous, but behind this it is broken or very faint. At the spiracular depression it begins again, and is continued back into the lateral line. Organ 17 is the only one in this length of canal that can be distinctly recognized. The lateral line extends beyond the anus, and the accessory lateral line not quite to it, as shown in Fig. 2. The dorsal body line begins opposite a bend in the main line a little in front of the point where the first organ of the lateral line will appear, and has already reached the top of the body, and turned backward along the edge of the dorsal fin. The end of the line is strongly swollen. Neither this line nor the supratemporal or middle dorsal pit lines are continuous at this age with the main lateral line. The supratemporal line shows two enlargements, from the median one of which the posterior pit line starts at a sharp angle. The middle dorsal pit line has a single well-developed organ, with the cord of the line extending on either side of it. The line of the mandibular canal is regularly developed to organ 10, the first two or three organs still being indistinct. The opercular part of the line is broken. Organ 15 and the rudiment of organ 16 lie above the horizontal cheek line, and separated from it and from organs 12, 13, and 14, none of which are fully developed. Organ 11 has not yet appeared. The vertical cheek line and mandibular surface line form a nearly continuous line, extending between organ 8 mandibular and 12 infra-orbital. The gular line could not be found.

In the 11½-millimetre specimen (Fig. 6, Pl. XXXI.) the cord of the infra-orbital line extends the whole length of the line, and is continuous with that of the lateral line. In this specimen

the dorsal body line is also continuous with the cord of the lateral line; the cord of the supratemporal line, with organ 18; and the cords of the three dorsal pit lines and the lines on the cheek, with the canal organs, near which they arise. In slightly older specimens these connections disappear, and in still older ones even the cord connecting the organs of each line is traced with difficulty. In the 11½-millimetre specimen there are, behind organ 18 infra-orbital, five faint transverse markings, as shown in Fig. 6. The first one marks the hind edge of the extrascapula, and the others the lines of intermuscular septa. Between the fourth and fifth lies the first regular organ of the lateral line. Between the others, organs 19, 20, and 21 will doubtless appear; but this could not be established, for when these organs are first seen, the intersegmental markings have disappeared.

General Summary.

The sense-organs of the lateral system in Amia are separated by their position and by their innervation into distinct groups. Each group develops from a special cord of cells lying in the deeper layers of the epidermis, and each cord from a special sensory thickening, which when first seen from the surface in specimens hardened in chromic or picro-sulphuric acid, appears as a large, whitish, and slightly raised spot. These spots are the rudiments, not only of the different groups of organs, but also, according to the theory of Beard and others, of the nerves supplying them. They are all distinctly recognizable before the close of the first day after hatching. From them are developed the following groups of organs: —

1. The first sixteen organs of the infra-orbital canal, and the one organ of the spiracular canal, all innervated by the *R. buccalis facialis*, and its posterior division, the *R. oticus*.

2. The seven organs of the supra-orbital canal and those of the anterior dorsal pit line, all innervated by the *R. ophthalmicus facialis*.

3. The sixteen organs of the operculo-mandibular line and those of the two pit lines on the cheek and the one on the mandible, all innervated by the *R. mandibularis externus*.

4. Organ 17 infra-orbital and those of the middle dorsal pit line, all innervated by the dorsal branch of the *N. glossopharyngeus*.

5. Organs 19 and 18 infra-orbital, the three organs of the supratemporal cross-commissure, and those of the posterior dorsal pit line, all innervated by a dorsal nerve arising from the ganglion or root of the *N. lineæ lateralis.*

6. The organs of the lateral line of the body, organs 20 and 21 infra-orbital, and those of the accessory lateral and dorsal pit lines of the body, all innervated by branches of the *N. lineæ lateralis.*

All these organs in the early stages of their development lie below the surface, but they soon push through the overlying epidermal cells, and their upper central portions become exposed. Each pit organ subsequently sinks slightly below the surface, and a little epidermal pit is formed above its central portion. The canal organs also sink below the surface, but they carry with them the surrounding tissues and by a process of infolding become inclosed in short canals, each containing a single organ. These short canals then become continuous, a single surface opening being left between every two consecutive organs along each line. These simple openings, or primary pores, may be retained in the adult, but most of them undergo a repeated dichotomous division, thus giving rise to groups of surface pores and to corresponding dendritic systems of canals.

By the union of the primary groups of short canals three principal canals are formed and two cross-commissures; namely, the infra-orbital or main canal, which is continuous with the canal of the lateral line of the body, the supra-orbital and operculo-mandibular canals, and the anterior and supratemporal cross-commissures. The anterior commissure has, following the terminology of other writers, been considered as a part of the infra-orbital canal. It lies over the snout, and connects the infra-orbital lines between organs 5 and 6, which are properly the first two organs of the line. The supratemporal commissure lies in the temporal region, and connects the main lines between organs 18 and 19, or directly opposite organ 18. The supra-orbital and operculo-mandibular canals have no connection with the corresponding canals of the opposite side. They arise as independent canals, but the supra-orbital, soon after its regular formation, anastomoses between organs 6 and 7 with the main canal between organs 14 and 15; and the operculo-mandibular, by its terminal opening, with the main canal between organs

16 and 17. These two anastomoses, and those of the anterior commissure with the infra-orbital, and the supratemporal commissure with the corresponding canal of the other side, are the result of the fusion of two primary pores which coalesce to form double pores, in the same way that two half-pores unite to form the primary ones. Double pores are formed in this way, and then disappear at the point where the anterior commissure joins the canal of the other side, and where the supratemporal commissure joins the main infra-orbital. One other anastomosis, formed in a somewhat different way between systems 6 infra-orbital and 4 supra-orbital, establishes a second connection between these two canals, and completes the circuit of the orbit.

There are on each side three lines of pit organs on top of the head, besides two on the cheek, one on the mandible, and one on the gular plate. The anterior and middle pit lines on top of the head lie nearly above the anterior and posterior semicircular canals. On the body there are two series of pit lines, one on the back and one accompanying the lateral canal.

In the adult the main canals lie in the deeper layers of the dermal bones. In larval stages they lie in open channels, or in bony tubes on the upper surface of these bones. Although some of the primary tubes issue through the bone, one always issues between every two consecutive bones along each line.

The sense-organs always lie inside the bones. They are at first single, but by the formation of bud-like organs at each end of the original one, large groups are formed, which in certain stages resemble the nasal epithelium of Exocetus and other forms, as given by Blaue.

The nasal pits are inclosed in the same way that the lateral canals are, and the short canal so formed is at first continuous with the canal inclosing organ 5 infra-orbital.

The head, gill-covers, and gular plate are thickly covered with the surface sense-organs called by Merkel terminal buds, which extend also onto the body. They are innervated in large part by the trigeminal, but probably also by the ophthalmicus profundus, facialis, glossopharyngeus, and vagus.

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EXPLANATION OF PLATES.

Index Letters.

a. anal fin.
al. anterior dorsal pit line of head.
all. accessory lateral line.
allo. sense-organ of lateral line.
an, an.a. anterior nasal aperture.
ANG. angular.
ANT. antorbital.
av. auditory vesicle.
b., bf. ramus buccalis facialis.
c. caudal fin.
c.ll. canal of lateral line.
c.md. mandibular canal.
D. dentary.
dl. dorsal pit line of body.
dlo. sense-organ of dorsal pit line.
ep. epiphysis.
ETH. ethmoid.
ESC. extrascapula.
fgl. facial ganglion.
FR. frontal.
G. gular.
ggl. glossopharyngeal ganglion.
gl. gular pit line.
gu. gular plate.
hf. ramus hyoideus facialis.
hmf. truncus hyoideo-mandibularis facialis.
hl. horizontal line pit of cheek.
IOP. interoperculum.
ig. infra-orbital groups of pores.
io. infra-orbital sense-organs.
ip. infra-orbital primary pores.
$i^{17}\ om^{17}\ p.$ double pore at union of infra-orbital and operculo-mandibular canals.
$i^{17}\ om^{17}\ g.$ double group of pores at union of infra-orbital and operculo-mandibular canals.
$i^{22}\ ll^{1}\ p.$ double pore at union of infra-orbital and lateral line canals.
$i^{18}\ s^{7}\ p.$ double pore at union of infra-orbital and supra-orbital canals.
$i^{18}\ s^{7}\ g.$ double group at union of infra-orbital and supra-orbital canals.
$i^{8}\ s^{4}\ g.$ double group at union of infra-orbital and supra-orbital canals.
JG. jugal.
LA. lachrymal.
lb. surface organs.
li. line of infra-orbital canal.
l.md. mandibular line of pit organs.
l.om. line of operculo-mandibular canal.
l.p. line of antorbital cross-commissure.
l.s. line of supra-orbital canal.
l.st. line of supra-temporal cross-commissure.
ll. lateral line.
llg. lateral line group of pores.
llo. lateral line sense-organs.
llp. lateral line primary pores.
md.l. line of mandibular canal.
mef. ramus mandibularis externus facialis.
mif. ramus mandibularis internus facialis.
mf. ramus mandibularis facialis.
ml. middle dorsal pit line of head.
mx. maxilla.
MX. maxillar[illegible].
NA. nasal.
nll. nervus lineæ lateralis.
np. nasal pit.
nt. nasal tube.
omg. operculo-mandibular group of pores.
omo. operculo-mandibular sense-organs.
omp. operculo-mandibular primary pores.
OP. operculum.
opf. ramus opthalmicus facialis.
p. pectoral fin.
PA. parietal.
pl. posterior dorsal pit line of head.
pn., pna. posterior nasal aperture.
popf. pre-opercular fold.
POP. pre-operculum.

POR.[1] first postorbital.
POR.[2] second postorbital.
PSF. postfrontal.
$S^{1\text{-}8}$. scales of lateral line.
S.ANG. supra-angular.
SC. suprascapular.
SCL. supraclavicula.
sg. supra-orbital group of pores.
so. supra-orbital sense-organs.
sp. supra-orbital primary pores.
smf. supramaxillary furrow.
SOP. suboperculum.
SOR.[1] first suborbital.
SOR.[2] second suborbital.
spr. spiracle.
sp.o. spiracular sense-organ.
SQ. squamosal.
stg. supratemporal group of pores.
sto. supratemporal sense-organs.
stp. supratemporal primary pores.
st.gl. supratemporal branch of glossopharyngeal.
st.v[1]. supratemporal branch of vagus.
v. ventral fin.
vl. vertical pit line of cheek.
x. nerve to gular line of pit organs.

The numerals affixed to the index letters *g*, *i*, and *p*, along the infra-orbital line, should be increased by one, except in Pl. XXXVI., where the correction has been made by the lithographer.

For	$ip^{1\text{-}20}$	read	$ip^{2\text{-}21}$.
"	$ig^{1\text{-}20}$	"	$ig^{2\text{-}21}$.
"	$i^{14}s^{7}$ *p* and *g*	"	$i^{15}s^{7}$ *p* and *g*.
"	$i^{16}om^{17}$ *p* and *g*	"	$i^{17}om^{17}$ *p* and *g*.
"	ip^{21} and ig^{21}	"	$i^{22}ll^{1}$ *p* and *g*.

EXPLANATION OF PLATE XXX.

FIG. 1. Larval Amia, one day old, showing a stage in the development of the lateral line, preceding the appearance of definite sense-organs. ×40.

FIG. 2. Larva four days old. Sense-organs beginning to appear along the sensory lines of the head. The double line of the body has not yet completed its growth backward. Length 10mm. ×15.

FIG. 3*a*. Larva 40mm long. Lateral line has reached the rays of the caudal fin; and while the formation of sense-organs now begins to advance along the body lines, the more anterior organs of the head have already disappeared by inclusion in their respective canals. ×15.

FIG. 3*b*. Tail of a larva 21mm long, showing the extension of the lateral-line organs onto the caudal rays. ×15.

FIG. 3*c*. Tail of an adult ♀ 22½ inches long. Half natural size.

EXPLANATION OF PLATE XXXI.

FIG. 4. Side view of larva four days old (10^{mm} long). The surface organs appear in a line above and below the eye. ×40.

FIG. 5. Front view of same larva.

FIG. 6. Side view of larva six days old (11½^{mm} long). Lateral-line organs of head lying in half-closed canals. Surface organs multiplying. ×40.

FIG. 7. Front view of same larva.

EXPLANATION OF PLATE XXXII.

FIG. 8. Side view of larva 14^{mm} long, showing canals of head in various stages of formation. Surface organs have become numerous. ×40.

FIG. 9. Dorsal view of same larva.

EXPLANATION OF PLATE XXXIII.

FIGS. 10 and 11. Ventral and front views of the same larva. × 40.

EXPLANATION OF PLATE XXXIV.

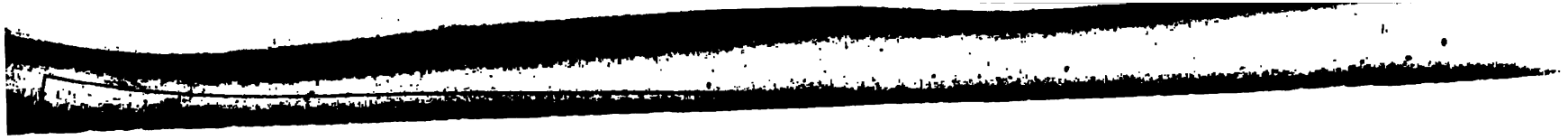
FIG. 12. Larva 18^{mm} long, showing the primary pores in various stages of formation. × 30.

FIG. 13. Larva 31^{mm} long, showing the primary pores of the head. × 30.

EXPLANATION OF PLATE XXXV.

FIGS. 14–16. Three views of a young Amia 78^{mm} long. The pores have begun to multiply by division. × 5.

FIG. 17. Young Amia 25^{cm} long. The primary pores are now represented by irregular groups of pores in different stages of division. × 3.



EXPLANATION OF PLATE XXXVI.

FIGS. 18 and 19. Young Amia, 13.6^{cm} long, shows most of the pores of the head divided into two, a few pores (*l!*) of the lateral line still single, and the surface organs of the dorsal line (*dl*). × 2.

FIGS. 21 and 22. Three views of the adult head. Natural size.

EXPLANATION OF PLATE XXXVII.

Surface views of the area between the eye and the first scales of the lateral line, taken at different ages, to illustrate the formation of the canal in sections, and the establishment of continuity between the sections by bringing two openings together to form one pore.

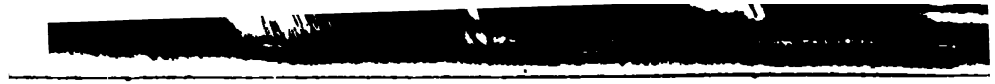
FIG. 23. From a specimen 19^{mm} long. ×40.
FIG. 24. From a specimen 20½^{mm} long. ×40.
FIG. 25. From a specimen 23½^{mm} long. ×40.
FIG. 26. From a specimen 26^{mm} long. ×40.
FIG. 27. From a specimen 29^{mm} long. ×40.
FIG. 28. From a specimen 30½^{mm} long. ×20.

EXPLANATION OF PLATE XXXVIII.

FIGS. 29–33 illustrate still later stages in the formation of the primary pores; and Fig. 34, the first division of these pores.

FIG. 29.	From a young Amia 35^{mm} long.	× 20.
FIG. 30.	From a young Amia 37^{mm} long.	× 20.
FIG. 31.	From a young Amia 40^{mm} long.	× 20.
FIG. 32.	From a young Amia 50^{mm} long.	× 20.
FIG. 33.	From a young Amia 54^{mm} long.	× 20.
FIG. 34.	From a young Amia 134^{mm} long.	× 8.

In Fig. 33, read *sp*^{8} for *ip*^{8}.



EXPLANATION OF PLATE XXXIX.

FIGS. 35–38, illustrate the formation of the lateral-line canal; and Fig. 39 shows the primary pores replaced by a group of pores in each scale.

FIG. 35. From a specimen 30½^{mm} long. ×40.

FIG. 36. From a specimen 35^{mm} long. ×40.

FIG. 37. From a specimen 40^{mm} long. ×40.

FIG. 38. From a specimen 60^{mm} long. ×20.

FIG. 39. From a specimen 69^{cm} long. Natural size.

EXPLANATION OF PLATE XL.

Illustrating the osseous canals and pores in the adult. × 2.

FIG. 40. Bones of the head separated, but in serial order.

FIGS. 41–43. Scapular arch.

FIG. 44. First four scales of lateral line.

EXPLANATION OF PLATE XLI.

FIGS. 45–47. Three views of the skull with the bones *in situ*, showing the course of the lateral canals and the dendritic systems of peripheral canals. Natural size.

FIG. 48. A longitudinal section of a portion of the lateral line. × 140.

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